Evaluation of tactile feedback on dwell time progression in eye typing

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Haptic feedback is known to be important in manual interfaces. However, gaze-based interactive systems usually do not involve haptic feedback. In this thesis, I investigated whether an eye typing system, which uses an eye tracker as an input device, can benefit from tactile feedback as indication of dwell time progression. The dwell time is an effective selection method in eye typing systems. It means that the user keep her/his gaze on a certain element for predetermined amount of time to active it. The tactile feedback was given by a vibrotactile actuator to the participant's finger that rested on top of the actuator.

This thesis reports a comparison of three different tactile feedbacks: "Ascending" feedback, "Warning" feedback and "No dwell" feedback (i.e. no feedback given for dwell), for the dwell time progression during eye typing process. The feedbacks were compared in a within-participants experiment where each participant used the eye typing system with all feedbacks in a counterbalanced order. Two sessions were conducted to observe learning effects.

The comparison methods consisted of quantitative and qualitative measures. The quantitative data included text entry speed in words per minute (WPM), error rate, keystrokes per character (KSPC), read text events (RTE) and re-focus events (RFE). RTE referred to the events when the participant moved the gaze to the text input field and RFE took place because the participant moved her/his gaze away from the key too early, thus requiring a re-focus on the same key. The qualitative data were collected from the participants' answers to questionnaires.

The quantitative results reflected a learning effect between the two sessions in all the three conditions. KSPC indicated a statistically significant difference between the feedback conditions. "No dwell" feedback was related to lower KSPC than "Ascending" feedback, indicating that "Ascending" feedback led to more extra effort by the participants. The result of qualitative data did not indicate any statistically significant difference among the feedbacks and between the sessions. However, more research with different types of haptic actuators is required to validate the results.

Key words and terms: dwell time, tactile, eye typing, gaze control

Preface

I started to work on this thesis around October 2012 and it took longer time than I expected to finish. The purpose of this thesis is a part of the research in the HAGI project of TAUCHI, which integrates haptics with visual interaction. There were various challenges on the way but fortunately I could get full help and support from my supervisors and other researchers in the TAUCHI research center.

I would first like to acknowledge my supervisors Päivi Majaranta and Prof. Poika Isokoski for the opportunity of working in such an interesting topic and their invaluable support and numerous fruitful discussions during the development of this thesis. I would also like to show my gratitude to Prof. Veikko Surakka for his precious advice on the thesis writing and experiment methods. Moreover, I appreciate the haptic technical support from Jussi Rantala, the experiment suggestions from Jari Kangas, the software support from Oleg Špakov and Deepak Akkil. Without them, I could not have finished my thesis work so smoothly. Furthermore, I thank all the participants who contributed their valuable time to my experiment.

These two years of studying in the University of Tampere and living in Finland is an unforgettable experience, with amazing fellowship and brothers and sisters, wonderful friendships, inspired cell group gatherings and a badminton group.

Finally, I am deeply indebted to my father Min Zhi who is no longer with us and mother Huiqin Jiang for their unconditional love. I also wish to express my deeply gratitude to my uncle Xiachen Zhi for his absolute support and sincere comments on my thesis writing. I could not have become what I am now without them.

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Contents

1. Introduction

Gaze based interactive systems utilize users' eye gaze (and movement) to control technology. The basis of eye typing is that "despite eyes being primarily a perceptual organ, gaze can be considered as a natural means of pointing" (Majaranta & Räihä, 2007). Previous studies have shown that some people can benefit from gaze based interactive systems greatly, such as people with ALS syndrome (Calvo *et al.*, 2008). ALS patients are the primary target user group of gaze based interactive systems. According to Wikipedia (Wikipedia, Amyotrophic lateral sclerosis), Amyotrophic lateral sclerosis (ALS) is a debilitating disease with varied etiology featured by rapidly progressing weakness, muscle atrophy and fasciculation, muscle spasticity, difficulty in speaking (dysarthria), difficulty in swallowing (dysphagia), and difficulty in breathing (dyspnea). ALS is the most common of the five motor neuron diseases..

Eye typing systems can improve the life quality of people with motor disabilities like ALS (MacDonald, 1998). They can allow the users to participate in the social activity to a fuller degree and also to have more access to social resources. In the past 30 years, several eye typing systems have been developed for people with special needs, as the review by Majaranta and Räihä (2007) showed.

The implementations of gaze based interactive systems have also developed very quickly. Gaze based interactive systems are not limited to eye typing systems. Some of the systems make use of users' gaze commands to interact with graphical user interfaces. For example, Istance, Spinner and Howarth (1996) discussed a way of using gaze commands to interact with standard Graphical User Interface (GUI). Eye Draw by Hornof *et al.* (2004) is a gaze based interactive system for drawing. This system utilizes users' eye pointing as a way to draw pictures on the screen. Gaze control can even be used in online virtual worlds (Bates, Istance & Vickers, 2008). These systems encourage us to do research on gaze based interactive systems, since they could be implemented for various functions and improve the life quality of people with motor disabilities. The focus of this thesis is eye typing. Research on eye typing systems can be a gate to research on other gaze based interactive systems. Target activation is used in many kinds of gaze based interactive systems. In eye typing systems it is used all the time. Therefore, eye typing makes a good platform for studying issues related to target activation. The findings can then be applied in other kinds of gaze based interactive systems.

Most gaze based interactive systems are based on the eye tracking technology. However, the basic problem is that the location of the gaze does not exactly reflect the user's intention to interact. The problem is called the Midas touch problem: "Everywhere you look, another command is activated; you cannot look anywhere without issuing a command" (Jacob, 1991). One important method for reducing the

Midas touch problem is using dwell time for selection. It means that if the user stares at a target area for predetermined amount of time (e.g. 1000 ms), the command of that area will be activated. That predetermined amount of time is called the dwell time.

This study aimed at exploring a previously unknown area of dwell time feedback, which employed tactile feedback as an indication of dwell time progression during eye typing. The goal was to find out whether tactile feedback for dwell time progression can help in making eye tracker controlled user interfaces better fit human capabilities.

Feedback is an indispensable part of human-human communication. Similarly, feedback is also essential in any interactive human-technology systems because the reaction from the technology can "tell" the users that the system is tracking the users' actions and receiving the users' commands. Feedbacks can also indicate what is going on within the system. For users with no previous experience of eye typing or dwell time, it is helpful to have feedback for dwell time progression (Majaranta & Räihä, 2007). Adding this kind of feedback can give the users information on focusing. They can move their eyes away from the key before the dwell time has expired if it is not their target. Most of the feedbacks used previously were visual and auditory. As the multimodal interaction has developed, other modalities should be taken into account. In this study, tactile feedback was applied.

A practical reason for using tactile feedback in eye typing systems is that there are problems with visual and auditory feedbacks in eye typing in the real life context. One of the shortcomings is the privacy problem when the user is using the on-screen keyboard of an eye typing system to enter secrets. For example, when the user is typing the password of her/his bank account on an ATM machine using eye typing (De Luca *et al.*, 2007), giving visual feedback for dwell time progression or confirmation for selection will disclose the password to anyone who can see the screen at the same time. A similar problem exists in speech feedback. Another problem for auditory feedbacks, which include speech and non-speech feedback, is that auditory feedback will create noise. When the system is deployed in a quiet public environment, the sound will disturb people nearby. If the user is using the eye typing system in a noisy environment, the auditory feedback from the system will be interfered by other sounds. Tactile feedback, on the other hand, has none of these problems. It is a quiet and secure feedback which will not be felt by others besides the user of the feedback device.

In addition to discrete tactile feedback, continuous tactile feedback for dwell time progression was also studied. To my knowledge, there is no prior research on continuous tactile feedback for dwell time progression. The only continuous feedback for dwell time progression is visual feedback (such as Hansen *et al.*, 2008), such as the system by Majaranta *et al.* (2009) provided animated circle drawing around the character to indicate dwell time progression.

The aim of this thesis was to study how tactile feedback affected the effectiveness, efficiency and user satisfaction in the eye typing process. My supervisor had already done research on the comparison of tactile, auditory and visual feedbacks for key selection in eye typing. Thus, the experiment here studied if tactile feedback can be useful for indicating the dwell time progression, and what kind of tactile feedback for dwell time progression is better for the users. In this study, the data were collected in an experiment which used three kinds of feedbacks. They were "Ascending" feedback, "Warning" feedback and "No dwell" feedback (i.e. no feedback given for dwell). The results included both quantitative data and qualitative data.

In Chapter 2, the feedbacks used by current eye typing systems will be summarized. Then, parameters used for measuring eye typing software, tactile stimulation and psychological research on human sensation and perception will be introduced. In Chapter 3, the feedback design process will be described in detail. The research methods will be explained thoroughly in Chapter 4 and then the experiment results will be reported in Chapter 5. After that, the results from the experiment and the participants' experiences will be discussed in Chapter 6. The conclusions and future work will be discussed in the last chapter.

2. Background

2.1. Feedback in eye typing systems

When using the eye gaze as a text entry method, the eye tracking system measures where the user looks at. Once the desired item is under focus, the user needs to confirm the selection. There are several methods for doing that. For example, the user can give a face gesture or eye gesture, such as frown or blink, as a confirmation. Sometimes the user can also stare at a certain element for predetermined amount of time ("dwell time") to confirm selection.

The system may provide feedback for both user's actions and system actions. For example, in Eye word processor (EWP) (Yamada & Fukuda, 1987), the system will highlight the column of letters by a frame around it. This is just the feedback for the system's action, which is column scanning in predefined rate. The system will list the letters of selected column horizontally, which is feedback for the user's selection. The feedback discussed here refers to the systems' feedback for users' actions. During the eye typing, the system may provide a number of different feedbacks (Majaranta, 2009): firstly, the feedback of "focusing", which is given when the user's eyes pointing at a key of the soft keyboard; secondly, the feedback of "progression", which is specially used in systems using dwell time for selection. The feedback in eye typing systems is important because when typing with eye gaze, the user cannot directly "touch" the target object physically, they need extra real-time information indicating the interaction between their action and the reaction from the system. As developers had noticed the importance of feedback in eye typing systems at very early stage, very few eye typing systems in the history did not give immediate feedback for users' actions.. Most of the eye typing systems provide visual feedback for focusing, progression and activation. Auditory feedback for activation is also often given.

2.1.1. Eye typing systems with visual feedbacks

Most of the eye typing systems give visual feedback for users' actions. The reason is that visual feedback is the most intuitive feedback which uses the same modality as the control channel (visual channel). In the description in this section, the names of the feedback which first appear in the text are in italics. Only a part of features of the feedback in each system are highlighted but it does not necessarily mean that is the only feedback given by the system.

The first version of ERICA (Hutchinson *et al.*, 1989) which was delivered in 1988 is one of the earliest eye typing systems. This system adopted a tree-structured keyboard. The main keyboard had only 6 items. When the user's eyes fixated at one of the items, a sub keyboard with individual letters automatically appeared. The arrangement of the letters was according to the frequency in English, leading to increased typing speed (Frey, White & Hutchinson, 1990). The *pop up of the sub keyboard* was the visual feedback for user's focus.

When using the Eye word processor (EWP) (Yamada & Fukuda, 1987), a frame moves over columns at a pre-determined rate. When the frame is around the desired column, the user can select it by staring at the "input" key for more than 200 ms. Then only the characters in that column appear horizontally on the screen and a smaller frame moves over one by one in a pre-determined rate. The user can select the desired character by staring at the key of "input" longer than predetermined amount of time when the frame is around that desired character. This system uses special area for selection and gives feedback by *listing only the characters of the selected column horizontally* when that column is selected (Figure 1).

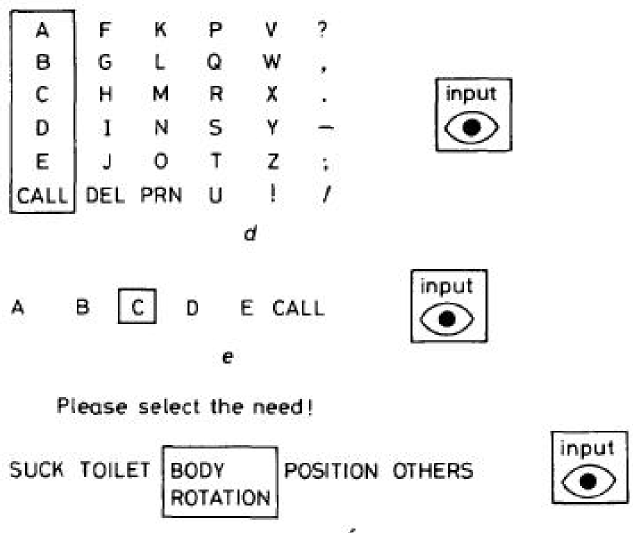

Figure 1. A small frame moves over columns and letters at a pre-determined rate in EWP (Yamada & Fukuda, 1987)

Besides using dwell time as selection, one method for reducing Midas touch problem proposed by Huckauf *et al.* (2005) is using "anti-saccades for selection". When the user looks at one object, a copy of it appears at one side of that object. The user should look towards the side opposed to that copy to trigger the selection action. The results of the study (Huckauf, 2005) showed that anti-saccades generated more errors than the way of using dwell time but it was much faster. It was "easy to learn, fast to fulfill, and can become an alternative selection mechanism for gaze controlled systems" (Huckauf, 2005). When using anti-saccades for selection, the *copy of the object* is the visual feedback.

Another method to avoid Midas touch problem is moving the eye point to "write" instead of using eyes directly pointing at the desired object. For example, EyeWrite (Wobbrock *et al.*, 2007; Wobbrock *et al.*, 2008) is a system which interprets the gaze movement into letters. After evolution of the design, the third design of the system draws stylized arcs between the corners and the corners are "simply hit-tested for the presence of gaze--when the gaze point enters a new corner, an arc is drawn there" (Wobbrock *et al.*, 2008). The user can also give the command of segmentation by returning eye point to the center of the input area. Other kinds of pauses do not trigger the command of segmentation. For example, the user can "pause to think" by leaving her/his gaze on the current corner. During the process, the system gives feedback of eye pointing by *drawing the arcs* between the corners (Figure 2). The eye movement between the corners will be interpreted into letters according to the letter chart (Figure 3).

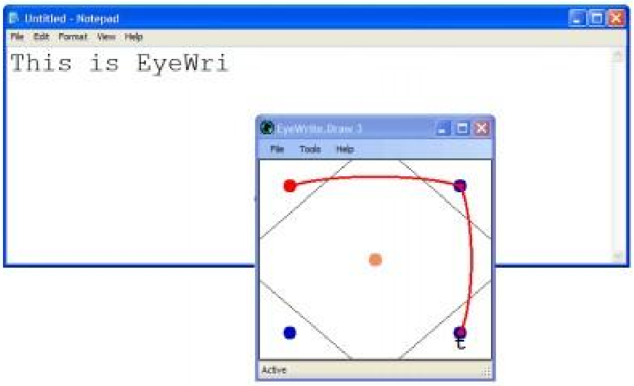

Figure 2. EyeWrite using eye gestures for entering text (Wobbrock *et al.*, 2007)

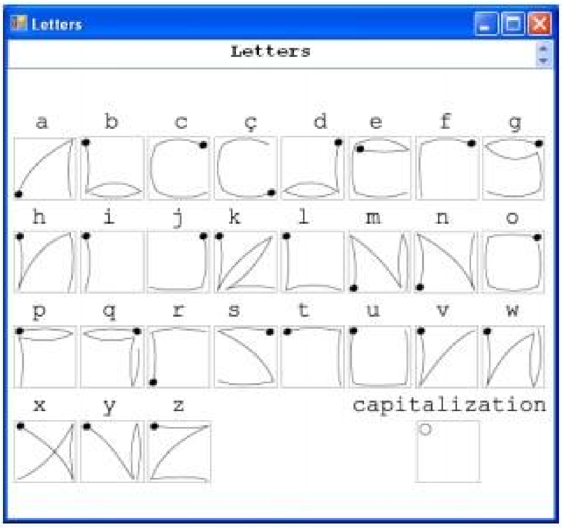

Figure 3. EyeWrite's letter chart (Wobbrock *et al.*, 2008)

Eye-S (Porta & Turina, 2008) is another similar system which uses eye point movement for "writing". The interface provides 9 points for the user's selection. The user can select different points and in different sequences to "write" different letters (Figure 4). *The sequences of pointing to the spots are indicated with different colors*, such as green in the first spot, yellow in the second spot and orange in the third one. Those color differences are the visual feedback of user's eye gestures.

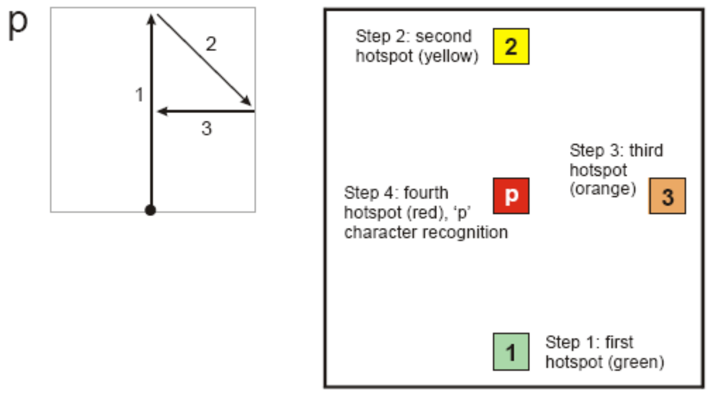

Figure 4. Example of feedback provided by Eye-S during the composition of letter ‘p’ (Porta & Turina, 2008)

Some eye typing systems use eye blink and frown as a method for activation. The tools of BLINKLINK and Eyebrow Clicker are introduced in a paper by Grauman *et al.* (2003). BLINKLINK detects the user’s voluntary blink and triggers the action of “click” in the system. As the name indicated, Eyebrow Clicker detects when the user raises her/his eyebrow and triggers the action of selection. Eye typing integrated with face gestures can be adopted by people with motor disabilities if facial muscles are still able to give gesture signals. Most common way to measure muscle activity is electromyography. The blinks and winks can also be detected from video signals (Majaranta & Räihä, 2007). In these systems, when the user is looking at some points of the “keyboards”, the targeted keys are highlighted. *Highlighting* is the visual feedback of pointing.

Dasher (Ward, Blackwell & MacKay, 2000; Ward & MacKay, 2002; MacKay, 2006) is an eye writing system with continuous selection movements. Instead of a stable keyboard (such as QWERTY), it uses a dynamic keyboard/key list which is ready for selection by gaze. The speed of entering for expert can be up to 35 words per minute. This is a little slower than typing on physical keyboard. However, it is quite fast among eye typing systems and head typing systems (Hansen *et al.*, 2004). It is “about twice as fast as and five times more accurate than any of the previous gaze writing systems” (Ward & MacKay, 2002). When the user is entering a text, the following letters for selection will move continuously towards the middle of the window. It is a kind of zooming process where the user continuously points at the moving letters by the eyes (Figure 5). It shows *continuous animated feedback* of the pointing process and selected letters.

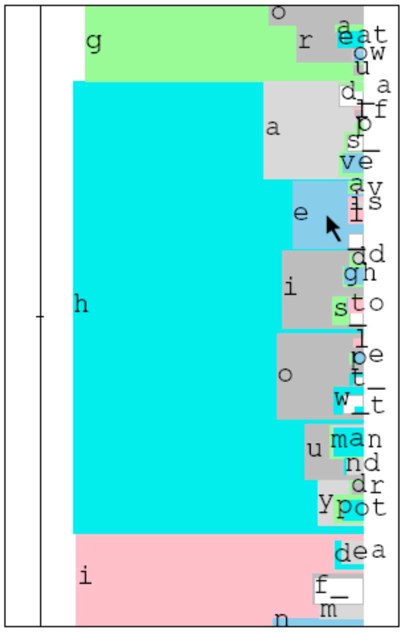

Figure 5. Screenshot of Dasher when the user begins writing hello (Ward & MacKay, 2002)

Stargazer (Hansen *et al.*, 2008) is another eye typing system that provides zooming and animated feedback. In Stargazer, the characters are arranged as a circle on the screen. The user looks at one character and the system zooms in that character. After the zooming process finished, the letter is selected (Figure 6). Stargazer highlights the character which is pointed by the user's eye point. In addition, it also shows *a small icon indicating the zooming process*.

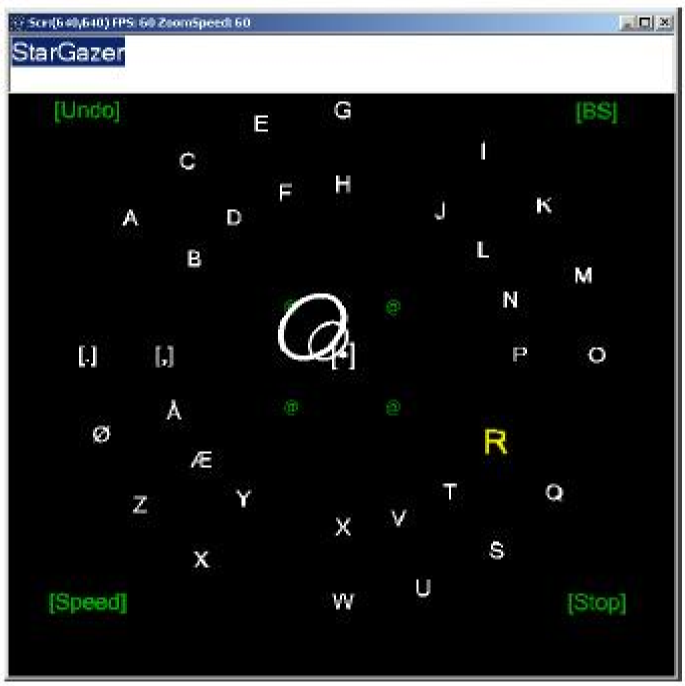

Figure 6. Stargazer (Hansen *et al.*, 2008)

The broader utilization of eye tracking in different applications requires higher resolution of detection of eye point movement. The resolution of tracking gaze can be a challenge in terms of capturing small eye movements (Majaranta & Räihä, 2007). However, high precision is not necessary for eye tracking when using on screen eye typing due to "natural language redundancy" (Hansen *et al.*, 2002). For example, the first version of Gazetalk (Hansen *et al.*, 2001) utilizes a 4*3 button grid, and the letters are distributed in the system in tree structure (similar with the ERICA system described above). The system of Gazetalk uses dwell time to trigger the action of selection. There will be a *status bar* (Figure 7) showing how much time remains before triggering the action of selection (Hansen *et al.*, 2003). This is a kind of visual feedback for the dwell time progression.

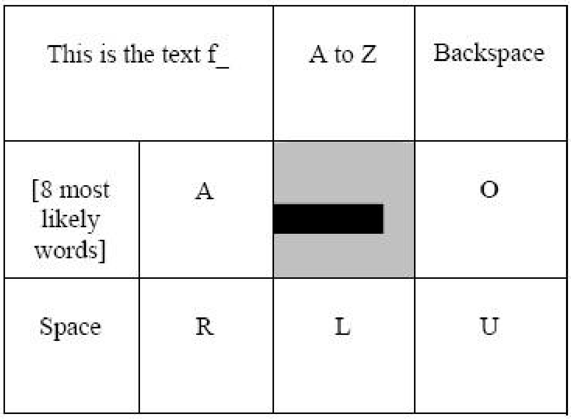

Figure 7. Status bar of the highlighted key in Gazetalk (Hansen *et al.*, 2003)

pEYE (Huckauf & Urbina, 2007) is "based on marking or pie menus which have already been shown to be powerful tools in mouse control". When using pEYE to enter text, the user first moves her/his eye point on the desired button on the screen, then that button will be highlighted and a sub-menu with sub-characters will pop out, the user can choose the desired character from the end level sub-menu.

I4Control (Fejtová, Fejt & Lhotská, 2004; I4CONTROL, 2008) is one of the applications which can be used as a substitution of mouse and keyboard. It measures the directions and movements of the user's eyes. The user can look up, down, right and left to move the cursor on the interface, and stop by moving the gaze to the central position or blinking. Blinking also triggers the action of selection. When using virtual screen keyboards, the users can move their eyes to manipulate the cursor to the desired key. Then the users can select the characters or commands by blinking. In this system, the users move eyes and give eye gestures to control the interaction, and the system gives reactions as moving the cursor in four directions and "clicks" the desired items. It does not use dwell time for selection, thus it does not require feedback for dwell time progression. However, since there is a special feature in this system: the cursor is controlled by the eye points similarly with the cursor controlled by joysticks, *the movement of cursor* is a kind of visual feedback for the eye point movement.

Another eye typing system which does not use dwell time is StarWrite (Huckauf & Urbina, 2007). This system is divided into two parts. The upper part is the non-traditional “keyboard” with all the letters arranged into a half circle. The lower part is text entry space. When the user is typing with her/his eyes, the gaze drags the desired letter towards the text entry space, then that letter will appear in the target text. The feedback of this system is also the highlighting of the desired letters and the *animation of moving the selected characters into the lower part of the screen*.

Quikwriting (Perlin, 1998), which originally is a stylus-based text entry system, can be modified into an eye typing system (Bee & Andre, 2008). In this adjusted system, the letters are distributed in the central circle area and divided into several sectors. When the user’s eye point moves to one sector, the letters in that sector will be enlarged separately around the central circle. Then the user moves her/his gaze to the desired letter and back to the central circle. The moving from the central circle to the letter and back to the central circle is the action of letter selection. In this system, the movements of eye points are indicated with the *animation of the enlargement*, this is the visual feedback of gaze and selection.

2.1.2. Eye typing systems with visual and auditory feedbacks

Audio in eye typing systems is often used as a complementary feedback to the visual feedback. There are mainly two kinds of auditory feedbacks, speech and non-speech. Speech feedback is reading out the selected character. Non-speech sound gives e.g. a short “click” to indicate the confirmation of the selection.

Actually, there is one system that used auditory feedback twenty years ago. That is the LC Eyegaze Communication System (Chapman, 1991). In this system, when the user looks at certain square for predetermined amount of time, the system will give the feedback such as changing the color of that square and the sound of “click” at the moment of selection. This is a kind of non-speech auditory feedback for confirmation.

Majaranta, *et al.* (2003) conducted a study by comparing several feedbacks of eye typing system, which include “visual only”, “speech only”, “click and visual”, “speech and visual”. “Visual only” shows an animation of a shrinking letter when focused. The color of the letter changes into red and the key is pushed down when selected. “Speech only” does not give any feedback when focused and only speaks out the letter when selected. “Click and visual” has similar feedback to “visual only”, adding only a sound of “click” when the letter is selected. “Speech and visual” has similar feedbacks as “visual only” with added speaking out of the letter when it is selected. The auditory feedbacks studied included speech and non-speech “click”. The system used in the experiment did not give any auditory feedback for dwell progression. The result of the study showed that “auditory feedback (click or spoken) is a more effective indication of selection than visual feedback alone”.

2.1.3. Summary of feedback and discussion

From the example feedbacks given above, it can be summarized that one of the most common feedbacks in current eye typing systems is visual feedback, which includes highlighting and some other color and shape changes. In a few eye typing systems and in the research field on feedbacks in eye typing systems, auditory feedback could be a complementary modality to improve the efficiency of interaction. However, touch is also another basic human sense. It is reasonable to consider using tactile feedback in eye typing systems. Thus, tactile feedback was studies in eye typing in this thesis.

2.2. Measurements in research on eye typing systems

Investigating the measurements which were used in studies on eye typing gives an overview of how researchers usually study eye typing. There are quantitative and qualitative measurements. The overview of the measurements is summarized in Table 1. The names of the measurements are in italics when they appear for the first time in this section.

Quantitative	Speed	Selection time
		Writing speed (WPM)
		Completion time
		Dwell time duration
	Error rate	Keystrokes per character (KSPC)
		Minimum string distance
		Intention propagation rate (IPR)
		False operation rate (FOR)
		Pointing accuracy
	Speed & Error rate	Measures based on Fitts’ law
	Gaze behavior	Read text events (RTE)
		Re-focus events (RFE)
		Inadvertent dwell clicks
		Gaze feedback point
Qualitative	Questionnaire	Fatigue before & after use
		Learnability
		Perceived performance
		Usability
		Life scale (SWLS)

		ALS questionnaire
		Ease of use
		Preferences
		System attractiveness
		N.A.S.A. ‘task load index’ (NASA-TLX)
	Interview	

Table 1. Overview of different measurements

2.2.1. Quantitative

The most useful quantitative parameters for investigating the usability of the eye typing systems are *speed* and *error rate* (Ware & Mikaelian, 1987; Porta & Turina, 2008; Huckauf *et al.*, 2005; Majaranta *et al.*, 2006). Speed includes some measurements such as *selection time* (Ware & Mikaelian, 1987), *writing speed* (in words per minute, WPM) (Ward, Blackwell & MacKay, 2000; Porta & Turina, 2008; Huckauf & Urbina, 2008; Majaranta, Aula & Räihä, 2004; Majaranta *et al.*, 2006) and *task completion time* (Huckauf *et al.*, 2005). Error rate is also measured from several aspects, such as error rate which is defined as *minimum string distance* (Soukoreff & MacKenzie, 2001), *keystrokes per character (KSPC)* (Huckauf & Urbina, 2008; Majaranta, Aula & Räihä, 2004; Majaranta *et al.*, 2006), *intention propagation rate (IPR)*, which is the percentage of correct output out of total number of input (Hori, Sakano & Saitoh, 2004), *false operation rate (FOR)*, which is the percentage of false output out of total number of input (Hori, Sakano & Saitoh, 2004).

Some of the studies related to eye typing systems also studied the gaze behavior of the participants. In research on the effects of feedback and dwell time in eye typing, Majaranta *et al.* (2006) evaluated the effects with five parameters, which included two measurements for gaze behavior, *read text events (RTE) (mean per phrase)* and *re-focus events (RFE).* RTE is the number of times the participant read the text entered during the eye typing process. It is a special measure for eye typing because frequent reviews of the user’s own work will lead to low efficiency and thus poor usability. RFE is the number of times the participant re-focused on a key to select it. Higher RFE will also lead to low efficiency and poor usability.

Surakka, Illi and Isokoski (2004) introduced frown as a method of confirmation of selection. That study compared the new technology with conventional mouse clicks in two aspects, which were pointing task time and error percentage. In the end, results were analyzed using the *Fitts’ law*. Another example is testing the usage of fisheye lens in eye pointing process. In this study, the researchers also combined visual search and a Fitts’ law task for the participants (Ashmore, Duchowski & Shoemaker, 2005) besides the direct result of typing speed and error rate.

When measuring how adjustable dwell time can improve the effects of eye typing, Majaranta, Ahola and Špakov (2009) not only calculated the speed and error rates but also measured the *dwell time duration*. The possibility to adjust dwell time directly affected the typing speed. Shorter dwell time enabled faster typing.

The experienced and inexperienced users perform differently in the same system. Bates (2002) studied if certain problems of gaze based interactive system were resulted from the users' inexperience or not. In this experiment, the researcher got the data about *pointing accuracy (mm), inadvertent dwell clicks (per object)* and *gaze feedback point (per object)*. They were all collected to indicate the differences of performance between experienced and inexperienced users.

2.2.2. Qualitative

Besides the quantitative measurements, some experiments also have employed qualitative measures. Qualitative data are basically from *questionnaires* and *interviews* (Majaranta, Ahola & Špakov, 2009). The questionnaires usually include many variables. For example, they can be *fatigue level before and after use* (Huckauf & Urbina, 2007; Majaranta, Ahola & Špakov, 2009), *learnability, usability* (Miniotas, Spakov & Evreinov, 2003), *perceived speed, ease of use* (Majaranta, Ahola & Špakov, 2009), *preference, system attractiveness* (Huckauf & Urbina, 2007)

To evaluate the improvements of life quality when using eye tracking systems, the researchers mostly used the qualitative parameters to measure the life quality, which include *satisfaction with life scale (SWLS)* and *ALS questionnaire* (Calvo *et al.*, 2008).

Bates and Istance (2003) designed a questionnaire to evaluate the participants' satisfaction when comparing the head and eye controlled devices. The questionnaire was designed according to "ISO 9241 Part 9 'Non-keyboard Input Device Requirements' International Standard (Smith, 1996) and the *N.A.S.A. 'task load index'* workload questionnaire (Hart & Staveland, 1988)". They studied several factors for each of three sections: workload, comfort and ease of use.

Section 4.1 will introduce the measurements which were used in the current study.

2.3. Tactile stimulation and feedback

Touch is one of the oldest, most primitive and pervasive human senses. The organ that is most associated with touch is the skin and the skin is one of the bodies' largest and most complex organs. It helps us to learn about the world around us as a complementary modality for sighted people or the primary modality for some people with poor sight (and hearing). For instance, tactile interaction can help them "to enhance access to graphical computer user interfaces" and through increasing sensitivity "to enhance mobility in controlled environments" (Chouvardas, Miliou & Hatalis, 2005). There are two different kinds of touch, which are active touch and passive touch. Active touch focuses on the object properties and passive touch focuses on the sensation experienced. Tactile feedback is a kind of passive touch.

Tactile sensation is the sensation produced primarily by two different receptors in the skin, which are free nerve ending and encapsulated nerve ending (Swenson, 2006). Tactile sensation has three dimensions, which are tactile acuity, spatial acuity and temporal acuity. There are thresholds for tactile sensation, for example, detection threshold means the smallest detectable level of stimulus. There are three ways to reduce the detection threshold and increase the possibility to be detected. These methods include increasing the duration of the tactile stimulation, increasing the area of stimulation and increasing the temporal interval between two consecutive stimuli. Human sensitivity for mechanical vibration increases above 100 Hz and decreases above 320 Hz (250 Hz said to be the optimum) (Rantala & Raisamo, 2011). To reach the maximum possibility to be detected, the vibration in frequency of 250 Hz is used in this research.

There are many methods to provide tactile stimulation as a feedback modality. The examples include skin deformation, vibration, electric stimulation, skin stretch, friction (micro skin-stretch) and temperature. Each method has a specific actuator to produce the stimulation. In this research, EAI C-2 tactor (Figure 8) was used to produce vibrotactile feedback. Other actuators for tactile stimulation include linear motors, solenoids, piezoelectric actuators, pneumatic systems and shape-memory alloys.

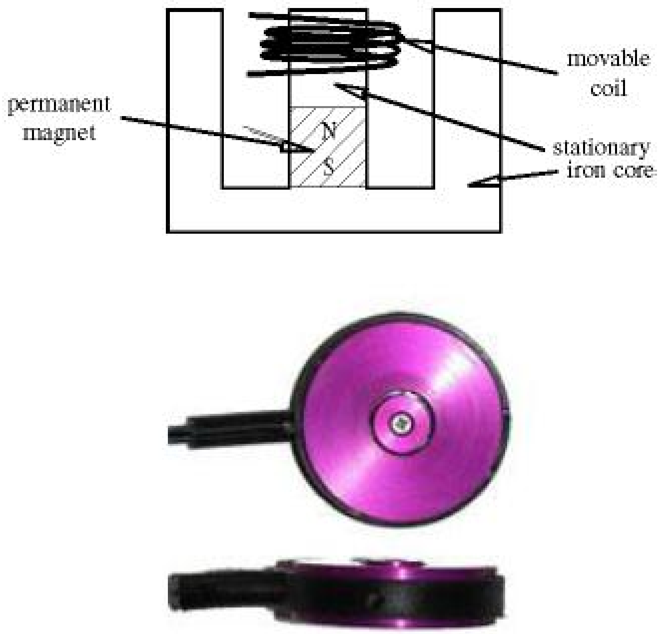

Figure 8. EAI C-2 tactor

The applications of tactile feedbacks include graphical user interfaces (Kieninger, T., 1996), reading systems, medical applications (Howe & Matsuoka, 1999), entertainment and educational applications (Challis & Edwards, 2001), military applications (Brewster & Brown, 2004) and tactile displays embedded in consumer electronics and wearable devices (Poupyrev, Maruyama & Rekimoto, 2002; Gemperle, Ota & Siewiorek, 2001). All these applications prove that tactile feedback can be an effective modality in the procedure of human-technology interaction.

Some of the above mentioned applications of tactile feedbacks can indicate the shape of the objects, some of them can indicate the texture of the objects, some of them can indicate the pressure of the objects and some of them can provide thermal information. Sometimes, the continuous tactile feedback can also indicate the time progression (Richter & Schmidmaier, 2012). As the subject of this thesis was the tactile feedback indicating the dwell time progression in eye typing, one continuous tactile feedback was used in the laboratory study.

2.4. Psychological research on human sensation and perception

In psychology, human sensation and perception are phases of processing human senses, such as visual, auditory and tactile senses. Sensation is the first phase in the functioning of senses to represent stimuli from the environment, and perception is a higher brain function about interpreting events and objects in the environment (Myers, 2004).

There are many psychological theories about human sensations and perceptions. Gestalt psychology is a theory about brain perception which is related to the research of multimodal interaction. "The operational principle of Gestalt psychology is that the brain is holistic, parallel and analog, with self-organization tendencies." (Wikipedia, Gestalt psychology). Gestalt psychology is often explained in the sentence of "the whole is greater than the sum of parts" (Hothersall, 2004). It is different from the theory of structuralism, which suggests the whole is the sum of parts. The most applications of Gestalt psychology are related to visual perception. However, the principle of Gestalt psychology, which means the self-organization tendencies of brain perception, can also be applied in other modalities in human perception and multimodal interactions. In multimodal interaction, the combination of different perceptions from different modalities can perhaps be re-organized in human brain and can provide a greater result than the sum of separated perceptions from separated modalities.

3. Feedback Design

Before deciding the detailed research method, it is important to decide what kinds of feedbacks for dwell time progression will be tested and compared. This chapter will describe the process of designing the feedbacks.

The tactile feedbacks in my experiment were produced by the wave form representing sound, and the sound was produced by the amplifier and the EAI C-2 tactor (Figure 8). Thus, in concrete terms the feedbacks were single-channel audio files.

Designing of the tactile feedbacks meant producing a waveform to be played through the C-2 tactor. The feedbacks were tested and revised according to the pilot tests and comments from pilot participants. The participants of the pilot tests were all from the Tampere Unit for Computer-Human Interaction (TAUCHI) so they are experts in human-computer interaction.

3.1. Dwell time duration

The time cost of dwell time is a significant cause of the slower typing speed in eye typing than in the normal keyboard typing. In the research of dwell time duration conducted by Majaranta, Aula and Räihä (2004), one of the results showed that the dwell time can be as short as 300 ms, which is enough for the skilled users to react and adjust the point of gaze. However, the beginners like the participants in this study were not experienced users of eye typing systems. They needed longer dwell time. Moreover, 300 ms is too short for the novice users to react to the presence or absence of tactile feedback. Therefore, tactile feedback on dwell time can be useful only to beginners who use a longer dwell time in the context of eye typing. This experiment was aimed at seeing if tactile feedback can help beginners.

Majaranta (2009) described the natural features of the eye in her dissertation. The duration which human eyes need to fixate an object to perceive it is between 200-600 ms. Because users may decide not to select that object after they perceived it, the given time for the perception and decision making should be above 600 ms, which is enough for most of the users. Therefore, dwell time was set above 600 ms in this experiment. However, too long dwell time may cause more fatigue. The typically used dwell time durations in experiments were between 500-1000 ms (for example, Hansen *et al.*, 2003; Istance *et al.*, 1996; Majaranta & Räihä, 2002). Based on the above mentioned previous research, the appropriate range for the dwell time duration was 600-1000 ms. The dwell time duration of the first two pilot tests was 800 ms, which was the middle number between 600 and 1000 ms.

3.2. Stage one: continuous feedbacks

In the normal process of eye typing, there are three types of feedbacks. They are for focusing, progression and activation. Providing different types of feedbacks at the same time may lead to a complicated result analysis, because the user perception for the feedback of progression may be affected by other types of feedbacks. For reducing this confusion, only the feedback for progression was designed in this stage. Because the feedback for the dwell time progression was tested and dwell time progression was a continuous procedure, the first idea about tactile feedback was using continuous vibrations. They were ascending vibration, constant vibration and descending vibration.

Human haptic receptors are more sensitive to some frequencies (depends on the actuator) than others. Sometimes the vibrations may not feel different between certain frequencies. In the experiment, the amplitude, instead of frequency, was descended and ascended. The frequency, waveform, amplitude, amplitude fade and duration of the vibrations were all set in the sound file generator internally and the actual outputs depended also on the sound card and amplifier settings. The frequency of the vibration for all the three feedbacks was 250 Hz and in sine waveform. The amplitudes of ascending and descending vibration were from 0 to 1 and 1 to 0 (1 is the maximum amplitude). The amplitude of constant vibration was 0.5. The duration of the tactile vibration was the same as the dwell time duration. Lylykangas *et al.* (2009) studied the vibrotactile stimulation in regulating participant's behavior. They used frequency as the verification element when ascending and descending the stimulation. The results showed that the stimulation with constant frequency was related to the highest accuracy but ascending and descending stimulations were more arousing than the constant frequency. Therefore, in this experiment, it was assumed that the ascending and descending vibrations would be more arousing than the constant vibration.

In this stage, tactile feedback test program (developed by TAUCHI researcher Jussi Rantala) which was based on Pd-extended version 0.43.1 (2013) (Figure 9) was used to create sound files. In this program, the waveform, frequency, amplitude, amplitude fade and duration were chosen directly from the menu. Three kinds of feedbacks for dwell time progression were compared in this stage:

- Ascending vibration with waveform "sine", frequency "250 Hz", amplitude "0→1", and duration 800 ms.
- Constant vibration with waveform "sine", frequency "250 Hz", amplitude "0.5", and duration 800 ms.
- Descending vibration with waveform "sine", frequency "250 Hz", amplitude "1→0", and duration 800 ms.

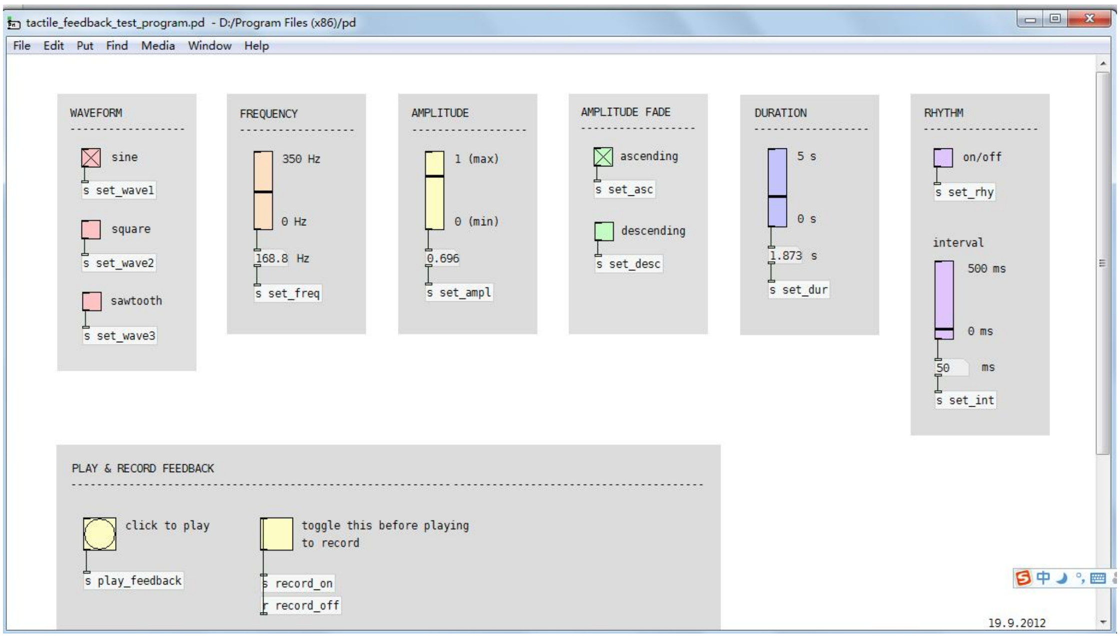

Figure 9. Pd-extended version 0.43.1, 2013

For the first and second pilot tests, the participants did not think that the feedbacks were worth comparing because they all felt similar. Moreover, because they were continuous and there was no independent feedback for selection, it seemed that the actuator was vibrating all the time and the participants could not differentiate feedback for different characters and complained that they were too noisy.

Furthermore, the participants also received unexpected vibration when their eyes moved away from the key. This was a feature in the software that was not suitable for tactile feedback. In practice, after the user moved to another key, they still received feedback from the previous key. Participants expected the feedback to stop immediately after they no longer focused on a key.

As a summary, the problems were:

- Continuous vibration might be too noisy. It was not easy to differentiate the ascending and descending vibrations when the actuator was vibrating all the time.
- It felt strange that there was no selection feedback, which made it difficult for the users to know if the key was selected or not.
- The participants received unexpected vibration when their eyes had already moved away from the key.

3.3. Stage two: "No dwell" feedback and selection feedback added

In stage one continuous vibration was not liked by the participants. Therefore, it was necessary to investigate whether the tactile feedback for dwell time progression was useful at all. Thus, in the second stage the goal was to compare tactile feedback for dwell time progression with tactile feedback for selection only.

Besides, the participants found that it felt strange to have no selection feedback after receiving the dwell time progression. The selection feedback was added in this stage.

In stage one the participants suggested that the vibration should stop immediately after the user moved her/his eye point away from the key. Therefore, the researchers in TAUCHI modified the software to a new version which can immediately stop vibration when the users' eyes move away from the key. To reduce the continuous vibration during the process of scanning on the keyboard, the software was changed so that the dwell progression began after the users looked at a key for 100 ms. This short delay before the dwell feedback started helped the participants to differentiate continuous feedback given for one key from the other.

Then the new sound files were created for all the feedbacks using Audacity version 2.0.2 (2013) (Figure 10). The vibration which indicated the confirmation of selection lasted about 50ms. As the user may not leave the key until the whole duration of selection finished, 50 ms was deducted from the duration of feedback, the feedback for dwell time progression in this stage was 750 ms. Since the feedback were given after the users looked at a key for 100 ms and there was also 100 ms delay in the sound files, the continuous feedback were given in (750 ms-100 ms-100 ms) =550 ms long.

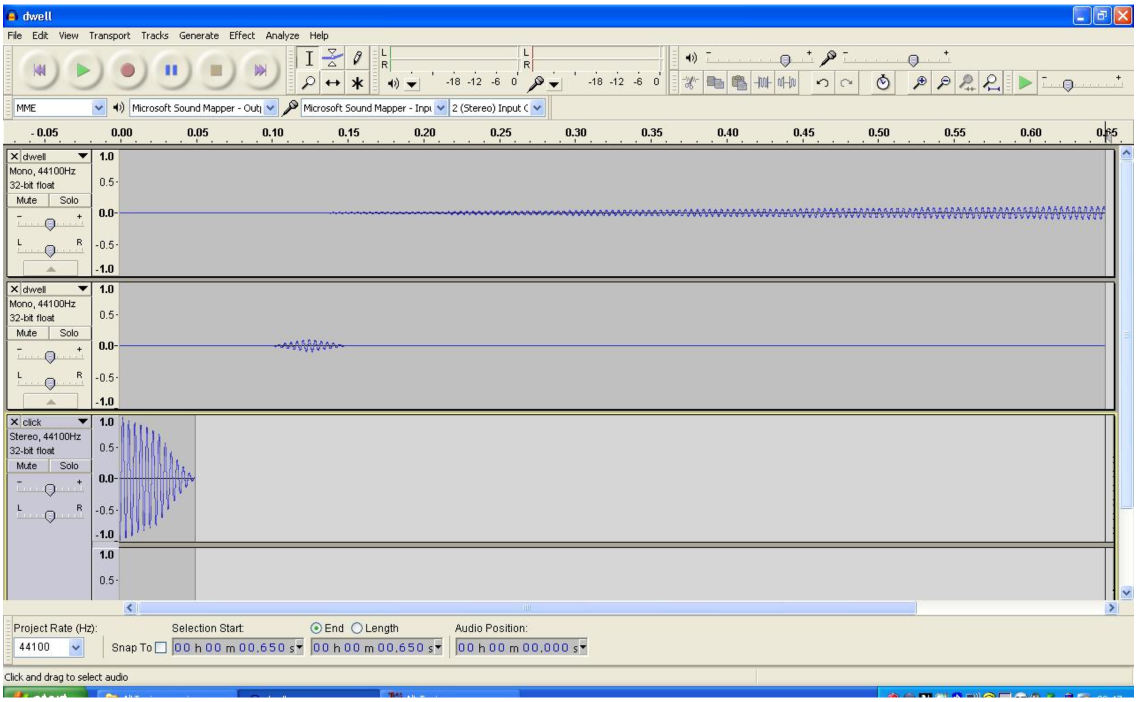

Figure 10. Screenshot of Audacity version 2.0.2 (2013) (the upper file is the ascending vibration, the middle file is the warning vibration and the bottom one is the selection vibration)

The amplitudes of the ascending vibration, the descending vibration and the constant vibration were fading in from 0 to 0.1, fading out from 0.1 to 0 and constantly 0.05 respectively. The amplitude of the click, which was a sharp vibration for confirmation of the key selection, was fading out from 1 to 0. The reason for selecting so much higher amplitude was the importance for the participants to be able to tell the difference between it and the end of the ascending vibration. The duration of the click was 50 ms. The frequencies of all these vibrations were 250 Hz.

Three pilot tests were conducted using these four kinds of feedbacks:

- Ascending vibration for dwell time progression and sharp vibration for selection, which was shortened as “Ascending”
- Descending vibration for dwell time progression and sharp vibration for selection, which was shortened as “Descending”
- Constant vibration for dwell time progression and sharp vibration for selection, which was shortened as “Constant”
- No feedback for dwell time progression and only the sharp vibration for selection, which was shortened as “No dwell”

The comments from these three pilot participants suggested that it was not necessary to compare the three kinds of continuous vibration for dwell time progression, as they felt the same. Therefore, the decision was to keep just one of them. Some pilots also claimed that the ascending vibration was a little more comfortable than the other two. Thus, the decision after this stage was to keep the “Ascending” and “No dwell” feedbacks.

3.4. Final stage: “Warning” feedback added

Another very insightful suggestion from one participant of the pilot tests was to add a “Warning” feedback. In it, there was a slight vibration indicating the start of dwell time progression. This suggestion was implemented in the final phase.

The frequency of the “Warning” feedback was also 250 Hz and it lasted for 750 ms in total. First there was a 200 ms silence (100 ms delay from system setting and 100 ms silence in file), then a 50 ms warning vibration, then there was a 500 ms silence and finally the selection feedback was 50 ms, which was the same as in the “Ascending” and “No dwell” feedbacks. The amplitude of the first vibration of “Warning” feedback was from 0 to 0.1 and back to 0, which had the largest amplitude in the middle of the vibration process (Figure 10, middle file).

As a result, three feedbacks were compared in the study: “Ascending”, “Warning” and “No dwell”, which represented the continuous feedback, non-continuous feedback and no feedback for dwell time progression respectively. These three conditions made it possible to compare different types of feedbacks more thoroughly and to get insight into what kind of feedback was best and preferred by the participants.

4. Method

4.1. Measurements

This study was aiming to evaluate tactile feedback on dwell time progression in eye typing. The independent variables included the feedbacks and sessions and the dependent variables included the following measurements.

First, the quantitative measurements that Majaranta *et al.* (2006) used were adopted:

1. **Writing speed in words per minute (WPM)**. Text entry speed is a very important indicator of efficiency of text entry. WPM is a measurement of the text entry speed. The "word" in "words per minute" is not the ordinary concept of an English word, but any combination of five consequent characters, including letters, spaces, punctuations, etc (MacKenzie, 2003).
2. **Error rate** can successfully reflect the effectiveness of the system interaction. In this experiment, the error rate was calculated by comparing the written text with the given text, using the minimum sting distance (MSD) method described by Soukoreff and MacKenzie (2001, 2003). The average error rate was figured out for each test (sum of per phrase Error rates for one test/the number of the phrases the participant entered for that test).
3. **Keystrokes per character (KSPC)** (MacKenzie, 2002; Soukoreff & MacKenzie, 2003) is another measurement which measures the keystroke actions caused by error correction in eye typing. KSPC investigates the average number of keystrokes used to enter each character, which includes letter, space, punctuation, etc. The optimal number of KSPC was 1. In this case each key press triggers entering of a character. However, if the user makes a mistake during the text entry process and corrects it, the KSPC will be greater than 1. For example, if the user is writing "mistake" and she/he makes a mistake, then the entry process will be m-i-s-t-i-[del]-a-k-e. The error rate will be 0, but the KSPC will be 9/7=1.29. "KSPC is an accuracy measurement reflecting the overhead incurred in correcting mistakes."(Majaranta, 2009). The average KSPC was calculated for each test (sum of per phrase KSPC for one test/the number of the sentences the participant entered for that test).
4. **Read text events (RTE)** is a measurement that describes the gaze behavior of the participants, especially the number of events when the gaze switches from the keyboard to the text entry space. High frequency of switching eye points to the text entry field is partially due to the uncertainty, which leads to worse interaction. This parameter could show in which condition the feedback makes the users more sure about whether they had entered correct text or not. It is known that the inexperienced participants will read text more when they are entering text (Bates, 2002). However, since none of the participants in this

experiment had experience with eye typing, the effect of skill did not affect the result of RTE comparison. RTE was normalized and reported on a per-character basis. The calculation meant that RTE was a ratio of the number of read text events to the number of keystrokes.

5. **Re-focus events (RFE)** is also a measurement that describes the gaze behavior of the participants. It measures how many times the participant focuses on one key to select that key. The ideal number of RFE is 0, which indicates that the user only focused each key once to select it. However, if the system cannot give clear feedback to the user for selection, or if the dwell time is not suitable for triggering selection, users may re-focus a key to finally select it. High frequency of re-focuses on one character is partially due to the uncertainty they felt for triggering the character and the unsuitability of the duration of the dwell time, which lead to worse interaction. RFE was also normalized and reported on a per-character basis. The calculation indicated that RFE was a ratio of the number of re-focus events to the number of keystrokes.

Besides these quantitative data to study user performance, also the subjective perception on the feedbacks was studied through questionnaires and interviews. The qualitative parameters in accordance with Bates and Istance (2003) were adopted. The questionnaire (Appendix 5) which was presented immediately after each condition consisted of the first four categories introduced below. Each category included several questions related to that category. The last questionnaire (Appendix 6) for comparison included the questions introduced in the fifth category. These five categories were listed as following:

1. **Workload**. Some questions which were feasible for this research were selected from N.A.S.A. 'task load index'(Hart & Staveland, 1988). Workload included six aspects in the questionnaires (Appendix 5), which were mental demand, physical demand, effort, temporal demand, frustration level and performance.
2. **Comfort**. In eye typing, comfort level was mainly related to the eye comfort. Although it was not very comfortable for people to use eyes for control in comparison to hand control, the proper feedback may increase the comfort level. If so, we can compare the feedbacks through the comfort level of eyes. The higher the rating was, the better the feedback was. The comfort levels of different tactile feedbacks were not included in the feedback questionnaire (Appendix 5) but they were compared at the end of each session in the preference questionnaire (Appendix 6).
3. **Ease of use**. In eye typing, ease of use indicated directly the usability aspect of the system. The perceived usability was sometimes different from what the quantitative data indicated, but also quite important for user experience. There were four questions related to ease of use in the questionnaire (Appendix 5).

The first three came from the questionnaire Bates and Istance (2003) used. They were perceived pointing accuracy, perceived text entry speed and the participant's feeling of system control. The last question came from what Lund (2001) suggested as a necessary item to measure usability, which was "simple to use". The feedbacks may affect the level of ease of use because the suitable feedback may improve ease of use, the participant's feeling of control, and simplicity.

4. **Ease of learning.** This measurement evaluated the subjective perception on learnability. Ease of learning was important to systems which were frequently exposed to novices. The ratings for ease of learning included the agreement level to two sentences, which were "It is easy to learn to use it" and "I use the system much faster in the end than in the beginning". The first sentence was the first feeling when the participants were exposed to the system while the second one was the durational feeling through the whole process. The higher the rating was, the easier it was to learn the system.
5. **Preference**. The preference comparison was collected at the end of each session by asking the participants to fill in the experiment questionnaire (Appendix 6) and through an interview. The questionnaire consisted of seven questions, which were related to preference, willingness for longer use, cognitive load, physical load, comfort, ease of use and learning. The participants were to choose one of the feedbacks according to the given question.

Each question in all of these measurements stated above (except the preference) was rated by the participants with a 7-point Likert scale. Then the ratings were summed up for each measurement.

Statistical differences were analyzed by a repeated measures ANOVA in all quantitative and qualitative measurements (except the preference). When the ANOVA showed statistically significant differences among the feedback types, pair-wise t-tests were used to pinpoint the differences between the feedback types.

4.2. Apparatus

The experiment was conducted at the gaze lab of TAUCHI. Tobii T60 gaze tracker was used to record the participants' eye movements. When the participant was seated in front of the screen of the Tobii T60, the distance between the user's eyes and the eye tracker was about 65 cm (Tobii, 2011). Tobii T60 eye tracker's screen was the primary screen and a Dell laptop was used as the host computer. During the tests, an additional monitor was used by the researcher to observe the behavior of the participants.

In the experiment, Alt typing developed by Oleg Špakov (2013) was used for eye typing. The layout of the keyboard was similar to the QWERTY keyboard. However, because only a part of the punctuations were needed, positions of some keys were rearranged (Figure 11). The background color of function keys such as backspace and shift was light green, which was different from the other keys. After the shift key (the one at the bottom right of the keyboard) was activated, the next letter would be capital letter. The key with smile icon, which meant loading the next phrase, was located at the bottom left of the keyboard, away from the other keys. This was because the action of pressing that key cannot be retracted. An accidental activation would lead to an unrecoverable error. All punctuation characters in the phrase set appeared on the keyboard. When the participant stared at one key for 100 ms, that key would be highlighted by changing the background to a darker color. The visual feedback was added because the comments from pilot participants indicated that it is better for the users to know if the system was correctly tracking their gazes. The tactile feedback cannot provide this information. As participants could not select text in the writing space and pressing the backspace key (the one located above the shift key) only deleted the last character, they were not able to delete the letter in the middle of the sentence to correct the writing.

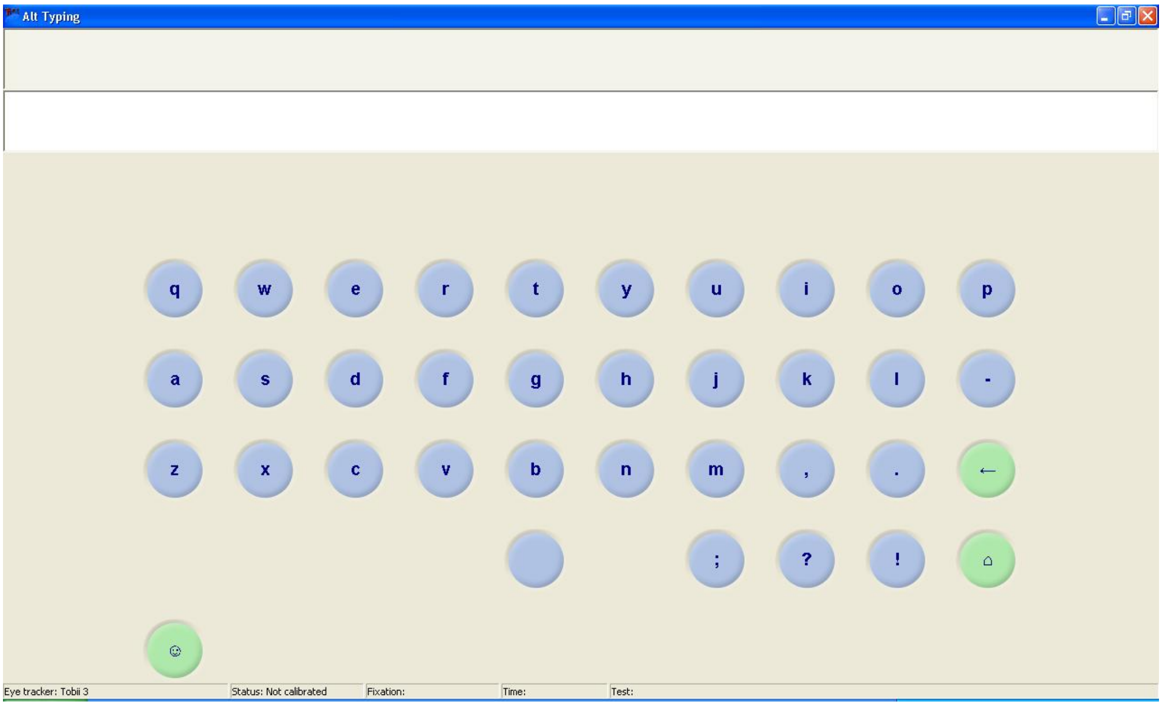

Figure 11. The interface of Alt typing

The source text and the target text were shown in the same height, padding, font and size. The source text was in black color and the target text was in red color. The background color for the source text was light gray and for the target text it was white.

The tactile actuator in the experiment was EAI C-2 tactor (Figure 8) which represented Windows Waveform (WAV) audio files played through a sound card in the computer. The tactile actuation was amplified through GIGAPORT HD audio interface. The size of the actuator was 3.05 cm in diameter and the vibrating area was 0.76 cm in diameter. According to the experience from previous tests, it was known that some participants may feel tickle if the device was fixed on the back of their hand. Thus, in this experiment, the actuator was put on a small soft cushion to reduce the sound of vibration and the participants were asked to put their index finger on the actuator to perceive the vibration (Figure 12).

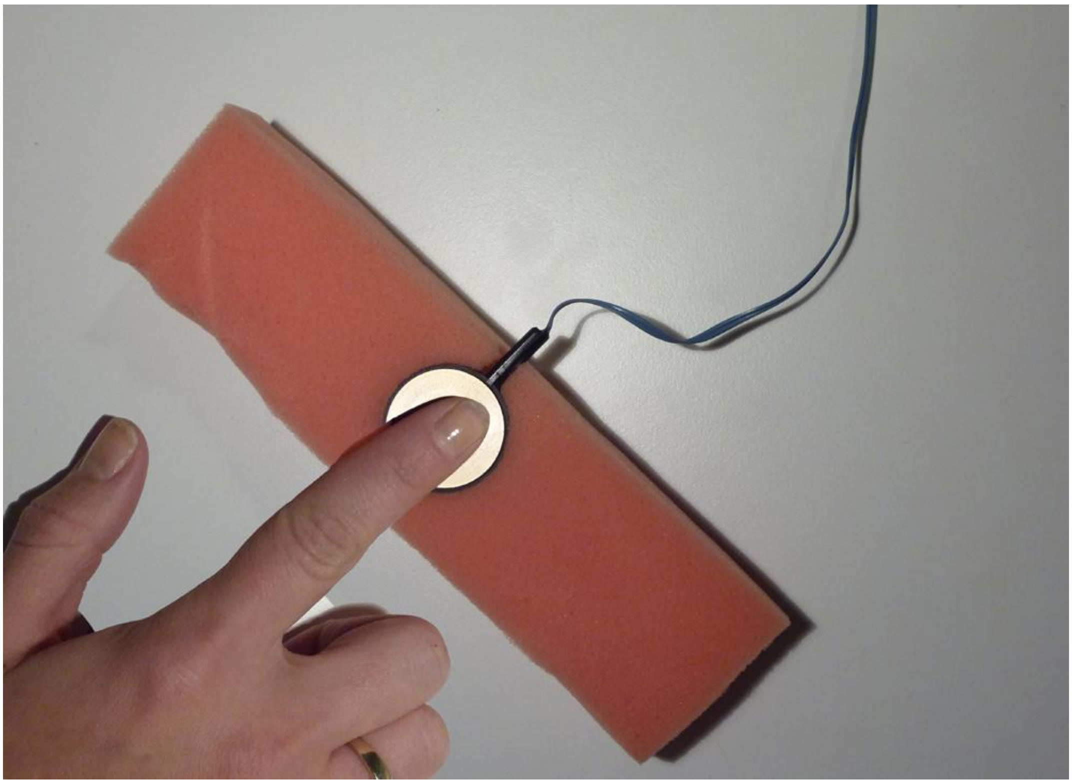

Figure 12. The finger on the actuator

4.3. Procedure

There were two sessions in the experiment and each participant took part in both sessions on two different days.

The first session was conducted as follows. First, the participant was guided to sit down in a fixed position in front of the Tobii T60's monitor. Then the participant was asked to read the "Informed consent form" (which was according to the sample from the book of Paper Prototyping by Carolyn Snyder (2003)) (Appendix 3) to learn about the purpose of the experiment and participants' rights. If she/he agreed to go on, the form was signed and the "Background questionnaire" was filled in (Appendix 4). After that, the experiment procedure and the methods of using the devices during testing were introduced.

Prior to the real tests, the participant completed a short training. The training consisted of five minutes of entering phrases by eye typing. In the training, the feedback for dwell time was an animation which drew a circle around the character that the participant was looking at. The visual feedback in the training was aiming to train the participants to acknowledge the dwell time. After the training, the participant took three real tests which gave the three different feedbacks separately according to the order designed before the experiment. Before training and before each real test, the tracker was calibrated. Each test lasted for five minutes. In practice, the time was not exactly five minutes but at least five minutes. The participants were not interrupted during typing of the last sentence even if five minutes was reached. Instead, the test ended at the first sentence completion after the five-minute period had expired. Pauses between the sentences used by the participant to memorize the phrase were excluded from this time. The timer for five minutes only ran from the press of the first key until the loading of the next phrase.

The participants were asked to enter the text as quickly and correctly as they could. The system used a modified 500-phrase set which was based on the original set published by MacKenzie and Soukoreff (2003). It was modified to have correct capitalizations and punctuations. Error correction was possible by using the backspace key that deleted the previous character. The participants were supposed to correct errors if they identified the errors immediately after committing them. If much text had already been entered after the error, correcting it was not to be done. After each test, the participant filled in a questionnaire based on the feedback given in that test (Appendix 5). After all the three tests, the participant filled in another questionnaire for comparison of the three feedbacks (Appendix 6) and discussed their experience in an interview (Appendix 7) for about 5 minutes. During the interview, participants could freely express their opinions. The first session lasted for about 1 hour.

The procedure of the second session was similar with the first session. However, it did not include the training phase. The second session only included three real tests in the counterbalanced order, with questionnaires (Appendix 5 and 6) and interview (Appendix 7) to collect subjective experience. The second session lasted for about 30 to 40 minutes.

4.4. Experiment design

This experiment compared three conditions in two sessions. These three conditions were: “Ascending” feedback, “Warning” feedback and “No dwell” feedback. Each participant took part in two sessions with different orders of the conditions presented. Two sessions for each participant took place on two different days. The feedback type and session were the independent variables. The results from quantitative measurements and qualitative measurements which were stated in Chapter 4.1 were the dependent variables.

4.5. Participants

There were five participants in the pilot tests. The participants of pilot tests included both male and female. Most of them had previous experience with eye typing or haptic feedbacks. They helped me to identify the potential problems related to the experiment procedure, questionnaire design and system/environment setting before the formal tests start.

In the formal tests, there were twelve participants. Four of them were females and eight of them were males. No one had previous experience with eye typing. None of the participants were native English speakers. Ten of them were native Chinese speakers and two of them were native Finnish speakers.

In the second session the order of the feedbacks was changed according to the Counterbalanced Measures Design (Shuttleworth, 2009). In this case, all the orders of feedbacks were tested. Three types of feedbacks were assigned to the participants in each session and all kinds of orders were assigned with same number of times, therefore, 6*n participants were to be invited to this experiment. Thus, the decision was to invite twelve participants.

The participants were assigned the feedback orders as shown in Table 2. (A stands for “Ascending”, N stands for “No dwell”, W stands for “Warning”).

No.	Session 1			Session 2		
	F1	F2	F3	F1	F2	F3
1	A	N	W	W	N	A
2	N	A	W	W	A	N
3	W	A	N	N	A	W
4	A	W	N	N	W	A
5	N	W	A	A	W	N
6	W	N	A	A	N	W
7	A	N	W	W	N	A
8	N	A	W	W	A	N
9	W	A	N	N	A	W
10	A	W	N	N	W	A
11	N	W	A	A	W	N
12	W	N	A	A	N	W

Table 2. The order of feedbacks assigned to the participants

5. Results

Because there was one participant that experienced a very poor calibration, the data from that participant were excluded from analysis. Another participant was added to take her/his place. The analysis was based on 12 participants in total. In this chapter, the results will be presented in three sections, which are quantitative results, qualitative results and preference. The results from interviews are discussed in Chapter 6.

5.1. Quantitative results

The Alt typing automatically calculated the data related to the participants' performance, such as text entry speed and error rate. Quantitative results were summarized from these system calculated data.

5.1.1. Writing speed

In terms of the means, the "Ascending" feedback was related to the highest text entry speed in the first session (6.32 wpm) and the "Warning" feedback was related to the highest text entry speed in the second session (7.29 wpm). However, the ANOVA indicated that the differences among the feedbacks were not statistically significant ($F(2, 22)=0.326$, $p=0.725$).

As Figure 13 shows, all the conditions in the second session were related to higher text entry speed than in the first session, and "Warning" feedback improved most in the second session. The differences between the sessions were quite evident ($F(1, 11)=22.878$, $p=0.001$).

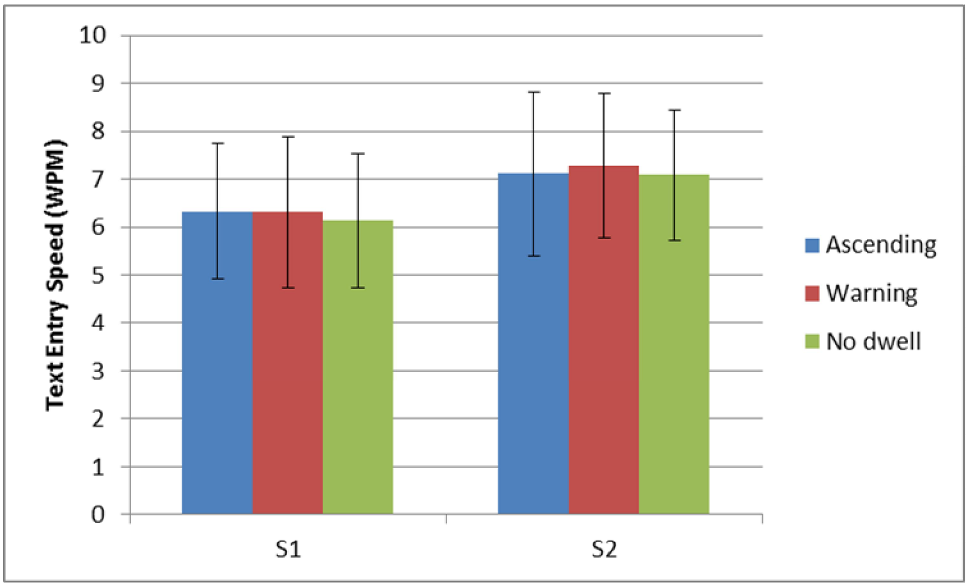

Figure 13. Writing speed for each feedback in sessions 1 and 2

5.1.2. Error rate

In the experiment, some errors were caused by memory errors. For example, in some sentences the participants added "the" in front of nouns. Some participants forgot to enter some words in the target sentences. These kinds of errors led to high error rate. However, these errors were not related to the feedbacks of the system. Thus, they were excluded from the calculation of average error rate (Table 3).

Source	SrcLen	Result
The four seasons will come.	27	The four seasons willbcojMe!-
Rain, rain go away.	19	Rain go away.
Please take a bath this month.	30	Please take bath this month.
longer than a football field	28	longer than football field
The fourth edition was better.	30	The fourth edition is better.
We dine out on the weekends.	28	We dine out on weekends.
I can see the rings on Saturn.	30	I can see the rings in the Saturn.
prevailing wind from the east	29	prevailing wind from east
He called seven times.	22	He called me seven times.
not quite so smart as you think	31	notquite smart as you tthink
The library is closed today.	28	The library is closed already.
Olympic athletes use drugs.	27	Olympic athletes drugs.
I cannot believe I ate the whole thing.	39	I cannot believe I ate the the whole thing.
I am wearing a tie and a jacket.	32	I am wearing atie and ajacket.

Table 3. The phrases that were not included in the error rate calculation

The “Warning” feedback was related to the highest error rate in the first session (1.02) while the “Ascending” feedback was related to the highest error rate in the second session (0.60). The “No dwell” feedback was related to the lowest error rate in both sessions (session 1 = 0.49, session 2 = 0.35). Nevertheless, the ANOVA indicated that the differences among the feedbacks were not statistically significant ($F(2, 22)=0.984$, $p=0.390$).

The tendencies seen from the column chart of Error Rate (Figure 14) showed that all the error rates in the second session were lower than in the first session. The “Warning” feedback improved most in the second session. However, this could be a random variation since the ANOVA demonstrated that the effect of session was not statistically significant ($F(1, 11)=1.543$, $p=0.240$).

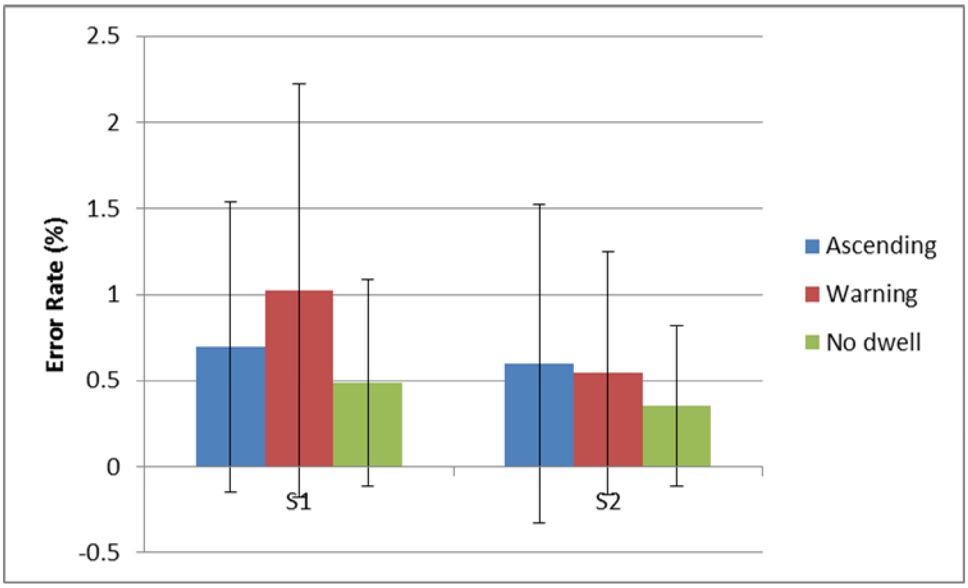

Figure 14. Error Rate for each feedback in sessions 1 and 2

5.1.3. Keystrokes per character (KSPC)

In the summary of KSPC, the phrases which were not included in the calculation of the error rate (Table 3) were also not included in the calculation of KSPC. The “Ascending” feedback was related to the highest KSPC (session1=1.10, session2=1.08) in both sessions and the “No dwell” feedback was related to the lowest KSPC (1.06) in both sessions. The main effect of feedback was also demonstrated in the ANOVA ($F(2, 22)=6.476$, $p=0.006$).

As Figure 15 shows, the “Ascending” and “Warning” feedbacks in the second session were related to lower KSPC than in the first session. The ANOVA demonstrated that the effect of session was not statistically significant ($F(1, 11)=0.426$, $p=0.527$).

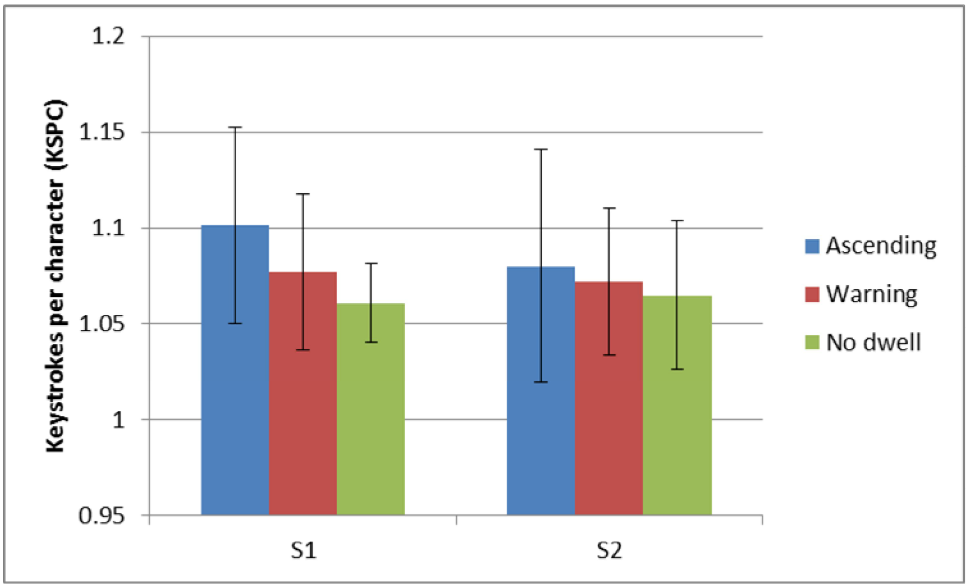

Figure 15. KSPC for each feedback in sessions 1 and 2

It was still not clear which feedback was different from the others or were they all different. Further pairwise testing (t-tests) was needed to pinpoint where the difference was. From the result of t-tests (Table 4), the difference between "Ascending" feedback and "No dwell" feedback in the first session was statistically significant ($t(11)=0.04$, $p=0.03$). Thus, the conclusion was that "No dwell" feedback was better than "Ascending" feedback in the first session from the aspect of KSPC. The differences between the others were not statistically significant.

P value	**A/W**	**W/N**	**A/N**
S1	0.16	0.24	0.03
S2	0.59	0.46	0.42

Table 4. Result of the T-tests of KSPC

5.1.4. Read text events (RTE)

The phrases which were not included in the error rate calculation (Table 3) were included into RTE calculation, because the memory mistake did not affect the result of read text events. The higher RTE reflected a worse feedback from this aspect. The "Warning" feedback was related to the highest RTE in both sessions (session1=0.49, session2=0.34) and the "No dwell" feedback was related to the lowest RTE in both sessions (session1=0.35, session2=0.30). Nevertheless, the differences among the three kinds of feedbacks were not statistically significant according to the ANOVA ($F(2, 22)=1.763$, $p=0.195$).

As Figure 16 shows, all feedbacks in the second session were related to lower RTE than in the first session. The RTE of "Warning" feedback had the largest gap between the first session and the second session, where noticeable improvement was speculated. However, the learning effect on "Ascending" and "No dwell" feedbacks were not very obvious. According to the ANOVA, the effect of session was not statistically significant on RTE ($F(1, 11)=2.013$, $p=0.184$). Generally, "Warning" feedback was related to higher average RTE than the other two feedbacks in both sessions. "No dwell" feedback was related to lowest average RTE in both sessions. However, the differences were too small to be statistically significant.

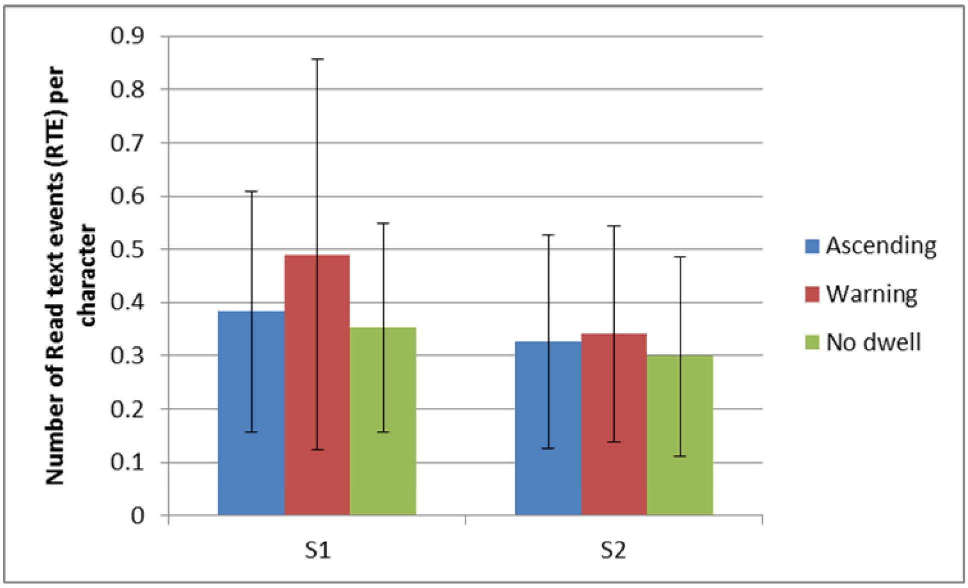

Figure 16. RTE for each feedback in sessions 1 and 2

5.1.5. Re-focus events (RFE)

The phrases which were not calculated into the error rate (Table 3) were included into RFE calculation. The memory mistake was not correlated with the result of re-focus events. The "Warning" feedback was related to the highest RFE in the first session (3.07) and the "No dwell" feedback was related to the highest RFE in the second session (2.34). However, the ANOVA showed that the effect of feedback was not statistically significant ($F(2, 22)=0.323$, $p=0.727$).

From the trends shown in the column chart of RFE (Figure 17), it could be speculated that all feedbacks in the second session were related to lower RFE than in the first session. According to the ANOVA, there was a significant effect of session ($F(1, 11)=17.506$, $p=0.002$). The RFE of "Warning" feedback had the largest gap between the first session and the second session, which indicated the most improvement.

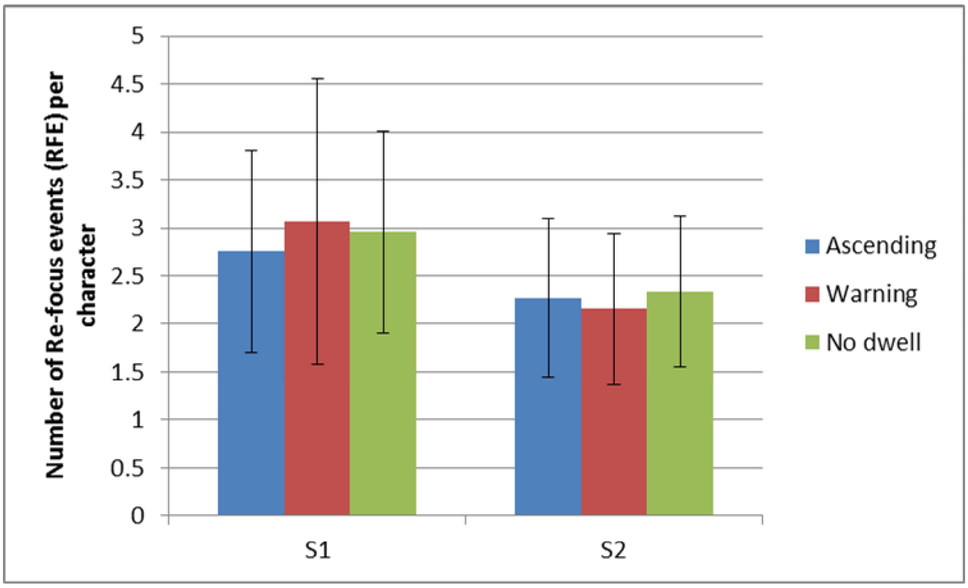

Figure 17. RFE for each feedback in sessions 1 and 2

5.1.6. Summary

As a summary of the quantitative results (Table 5), the effect of the session was statistically significant on WPM and RFE. The participants entered text significantly faster in the second session than in the first session using all feedbacks and they re-focused less on the keys. Effect of feedback was statistically significant on KSPC. "No dwell" feedback was related to significantly lower KSPC than "Ascending" feedback in the first session.

Measurements	Effect of Feedback	Effect of Session
Writing speed	Not statistically significant	Statistically significant
Error Rate	Not statistically significant	Not statistically significant
KSPC	Statistically significant	Not statistically significant
RTE	Not statistically significant	Not statistically significant
RFE	Not statistically significant	Statistically significant

Table 5. Summary of the quantitative results

5.2. Qualitative results

5.2.1. Workload

The ratings for each category in the questionnaire (Appendix 5) were summed up and then the averages of these sums for each session-feedback pair were computed. The higher rating in the workload category meant lower workload. In the first session, the "Ascending" feedback was related to the highest mean rating (30.83), which demonstrated the lowest workload. The "Warning" feedback was related to the highest mean rating in the second session (32.5). However, The ANOVA did not show statistically significant difference among feedbacks (F(2, 22)=0.157, p=0.856).

The differences of subjective perceptions on workload between two sessions could also be observed from Figure 18. From this chart, the “Warning” feedback was related to the largest improvement in the second session. However, the ANOVA indicated the effect of session was not significant (F(1, 11)=1.901, p=0.195).

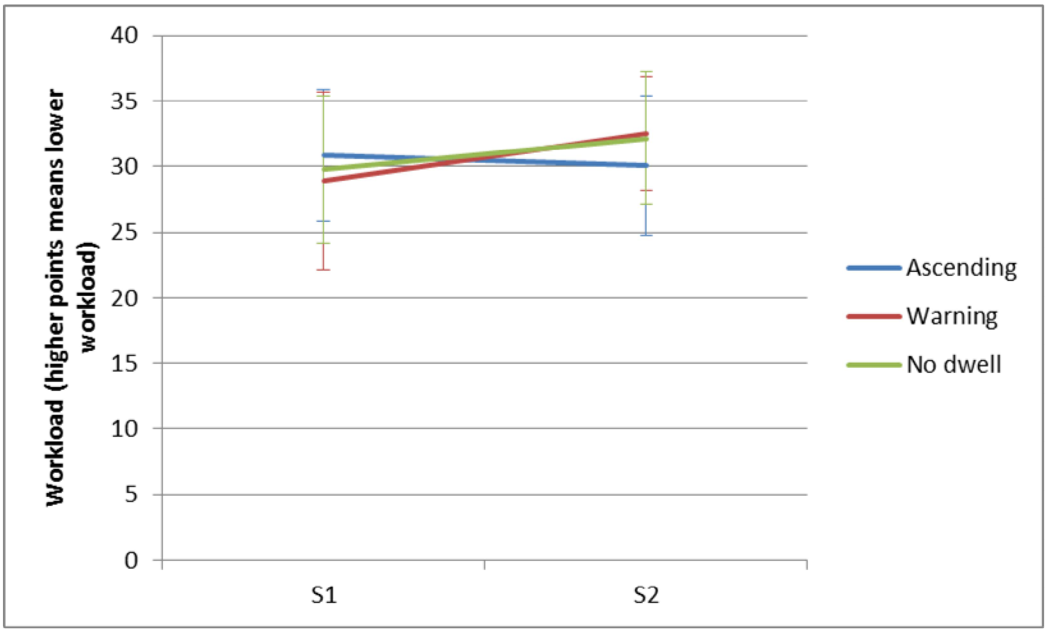

Figure 18. Workload for each feedback in sessions 1 and 2

5.2.2. Comfort

“Warning” feedback was related to the highest mean ratings in eye comfort in both sessions (session1=4.25, session2=4.08) and “No dwell” feedback was related to the lowest mean ratings in both sessions (session1=4.08, session2=3.58). However, the ANOVA indicated there was no statistically significant difference among feedbacks (F(2, 22)=0.557, p=0.581).

Figure 19 also shows strange perceptive differences between the two sessions in all three feedbacks: the perceived eye comfort was lower in the second session than in the first session. Maybe they were just random variations. The reason could also be the impatience after the participants mastered the usage of the system. Nevertheless, the ANOVA showed the effect of session was not statistically significant (F(1, 11)=0.930, p=0.356).

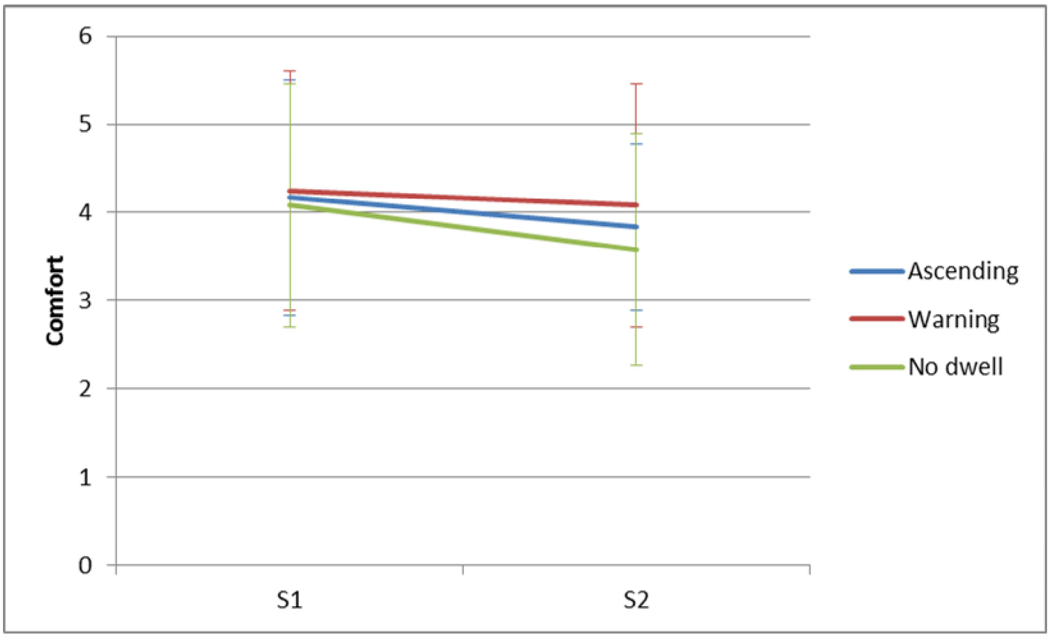

Figure 19. Comfort for each feedback in sessions 1 and 2

5.2.3. Ease of use

The “Ascending” feedback was rated as the easiest to use in the first session (21.25) and the “Warning” feedback was rated as the easiest to use in the second session (21.25). The differences among the average ratings of these feedbacks were not statistically significant ($F(2, 22)=0.615$, $p=0.549$).

The “Warning” feedback was perceived easier to use in the second session than in the first session, which was very obvious in Figure 20. This figure also shows strange differences between the two sessions in “Ascending” feedback and “No dwell” feedback. The participants felt it easier to use in the first session than in the second session when the system was giving “Ascending” feedback and “No dwell” feedback. The rank of feedbacks in the second session was just the opposite of the first session. However, all the differences between sessions may be just random as the effect of session was not statistically significant according to the ANOVA ($F(1, 11)=1.443$, $p=0.255$).

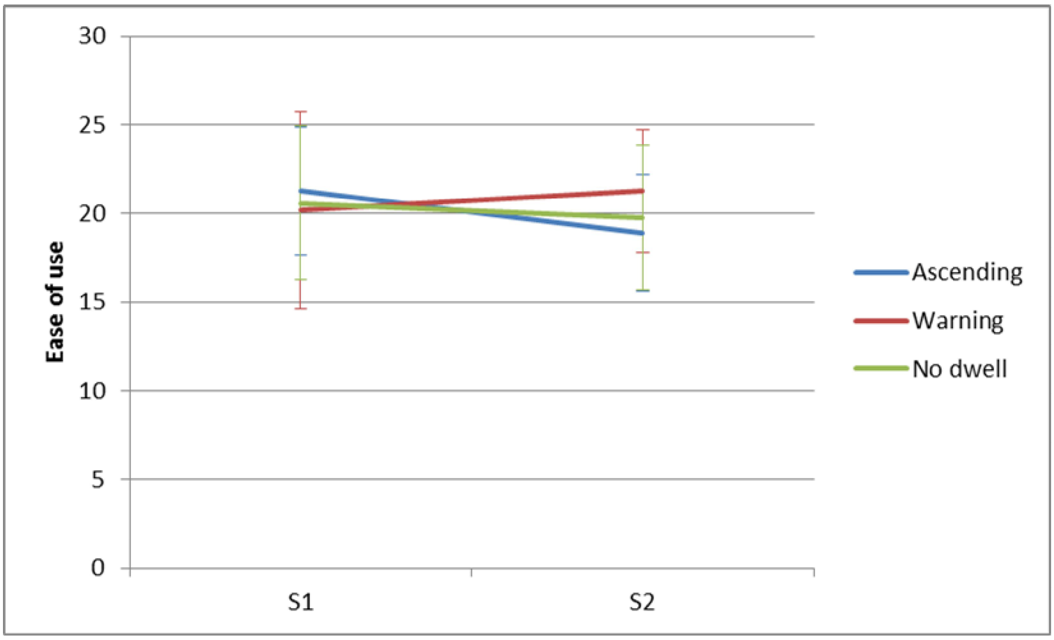

Figure 20. Ease of use for each feedback in sessions 1 and 2

5.2.4. Ease of learning

The "No dwell" feedback was related to easiest to learn in both sessions (session1=11.42, session2=11.50) and "Ascending" feedback was related to most difficult to learn in both sessions (session1=10.58, session2=11.08). It was interesting that the less tactile feedback led to easier to learn in typing. Nonetheless, the ANOVA indicated the effect of feedback was not statistically significant ($F(2, 22)=2.014$, $p=0.157$).

Figure 21 also shows learning effects between the two sessions in the feedbacks. They were all positive, but not statistically significant ($F(1, 11)=0.138$, $p=0.718$).

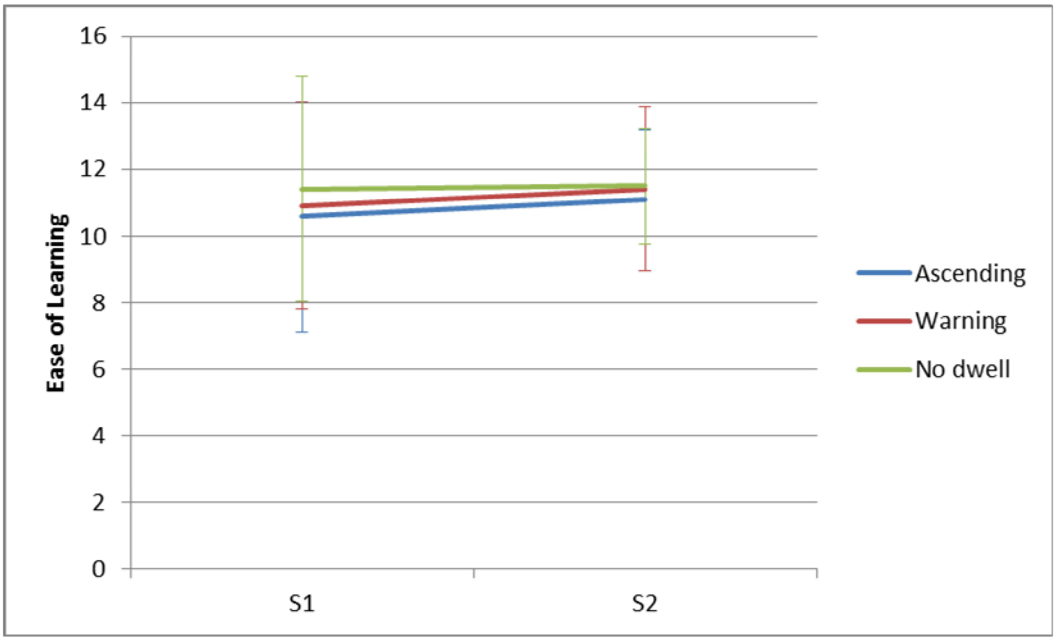

Figure 21. Ease of learning for each feedback in sessions 1 and 2

5.2.5. Summary

As a summary of the qualitative results, neither the effect of session nor the effect of feedback was statistically significant.

5.3. Preference

The number of marks in each cell of the preference questionnaire (Appendix 6) is listed in Table 6. In the first two questions, the participants expressed their general ideas about which feedback they preferred and wanted to use for longer time. Table 6 shows there was less preference of "Ascending" feedback in the second session than in the first one. Conversely, the preference of "Warning" and "No dwell" feedbacks increased.

	Ascending	**Warning**	**No Dwell**
Prefer	5	2	5
use for longer	6	1	5
lowest cognition	4	1	7
lowest physical	5	1	6
comfortable	5	0	7
easiest	6	0	6
easy to learn	4	0	8
Sum of session 1	**35**	**5**	**44**
Prefer	3	3	6
use for longer	2	2	8
lowest cognition	2	5	5
lowest physical	1	2	9
comfortable	3	2	7
easiest	3	2	7
easy to learn	3	2	7
Sum of session 2	**17**	**18**	**49**

Table 6. The results of the preference questionnaire

After the general ideas, the participants were asked to choose the best one from five secondary aspects, which were similar with the categories included in the questionnaire of each feedback (Appendix 5). It seemed that the "Warning" feedback was related to the greatest decrease at the second session for the cognitive load and "No dwell" feedback was related to the highest improvement at the aspect of reducing physical load. The "Warning" feedback was also related to more comfortable, easier to use and easier to learn in the second session than in the first session. The sum rating of "Warning" feedback increased sharply in the second session and the sum rating of "Ascending" feedback decreased sharply.

From the preference questionnaires, the “Ascending” feedback was not the best one among the three feedbacks, even in the first session. The “No dwell” feedback kept at the top of the rank although the preference of “Warning” feedback increased remarkably.

6. Discussion

The results indicated that the text entry speed was not associated with the type of feedback, while learning produced improvement in performance between sessions in all kinds of feedbacks. It was possibly owing to the similarity of the perception in the three feedbacks. They all included “click” feedback as the final confirmation of character entry. Some participants also indicated that they tended to ignore any other feedbacks before the final “click” vibration. In the experiment, the dwell time duration was fixed, thus the improvement of text entry speed was attributed only to the learning. The improvement indicated that in all feedback conditions, the participants could learn to enhance the text entry speed in a very short time. This kind of speed improvement was also indicated in the result from Majaranta *et al.* (2006), where the improvement of text entry speed was statistically significant in all conditions.

Comparing the error rate and RTE with the results of the first experiment of Majaranta *et al.* (2006), “No dwell” feedback was related to lower error rates in both sessions than the mean error rate of that previous study. The average RTE in all feedbacks and sessions were great higher than in that previous study (0.047-0.110 in their study versus 0.30-0.49 in the current study). The reason might be that Majaranta *et al.* (2006) used Finnish phrases with Finnish participants. When writing one’s own native language, one may not need to check the text letter by letter as one might when writing foreign text. Probably the spelling is harder for foreign words.

In this study, the ANOVA of the error rate and read text events (RTE) did not indicate significant effect of either the feedback or session. This suggests that the differences among feedbacks and sessions were not associated with the differences in error rate and RTE. The measurement of error rate only accounted for the uncorrected errors. Nevertheless, almost all the participants tended to correct all the errors they found when they were reading the target text (RTE) during the experiment. Although, they were told to enter text as quickly and correctly as possible, the observation showed that the participants tended to type correctly rather than quickly. Too much attention to the correction rate resulted in minor differences on error rate and RTE.

KSPC was the only measurement whose result showed statistically significant differences between feedbacks. “No dwell” feedback was better than “Ascending” feedback in the first session. Since KSPC measured extra work which was probably due to error correction, it appeared that the continuous vibration was not as good as “No dwell” feedback in error prevention for beginners. Except for the KSPC of “Ascending” feedback in the first session, all other feedbacks in both sessions were related to lower KSPC (1.06-1.08) than the grand mean KSPC (1.09) in the results of the first experiment reported by Majaranta *et al.* (2006). The tactile feedback might be related to lower KSPC than visual and auditory feedback.

The three feedbacks were not differentiated significantly in re-focus events (RFE). Although they all improved sharply in the second session, their improvements were independent of the feedbacks. RFE was not an effective measurement to differentiate different feedbacks in this experiment. However, Majaranta *et al.* (2006) found statistically significant differences on RFE between the different feedbacks in their second experiment. In their experiment, they compared two kinds of “visual + audio” feedbacks for a fixed duration of 900 ms. Thus, the reason for why RFE did not significantly differentiate the feedbacks in our experiment might include the different modalities of the feedbacks and the shorter duration of our feedbacks. Further experiment is needed to determine the reasons.

The “Warning” feedback was related to large variations among participants in error rate (max=4.02, min=0), read text events (RTE) (max=1.18, min=0.18) and re-focus events (RFE) (max=4.21, min=1.6) in the first session. It suggested that “Warning” feedback was related to different effects with different users. Prior to the design of the “Warning” feedback for a certain group of users in the future, a user study should be conducted to investigate whether the target group can perform well in the context provided with “Warning” feedback.

From the speculation on trends seen in the figures of the subjective feelings, the feedbacks were perceived differently from what the results of quantitative data revealed. Although the ANOVA showed no significant effect, the figures of the subjective feelings showed the trends that the “Ascending” feedback involved the least user workload and was the easiest to use in the first session. The speculation also included that “Warning” feedback demanded the highest workload and was the most difficult to use. This might be the reason why some participants had trouble telling apart the short warning versus selection. As Majaranta *et al.* (2006) discussed, giving separate feedback for focus and selection maybe confusing if they are not clearly distinguishable from each other. However, in the second session, the results were reversed in both measurements of workload and ease of use. It seemed that “Ascending” feedback was not suitable for long-term use and skilled users might prefer “Warning” feedback.

Regarding the opinions about the comfort and ease of learning, the differences between two sessions were so small that they did not have any statistically significant difference. From the speculation on the trends, the “Ascending” feedback was perceived more comfortable compared with “No dwell” feedback and “No dwell” feedback was the easiest to learn in both sessions.

There was a strange trend seen in Figure 19. The participants felt less comfort in the second session than in the first session. It might suggest that after the participants learned to use the system, they might want to speed up (reduce dwell time duration) (Räihä & Ovaska, 2012). They were not allowed to do that in this experiment, this may have increased frustration levels even if the system itself remained the same.

In the interview, some participants complained that the “Ascending” and “No dwell” feedbacks were sometimes felt too “pushing” and the “Warning” feedback was thus comparably comfortable. The “Ascending” feedback was sometimes pushing because it was vibrating all the time during the dwell time progression and the vibration was becoming growingly stronger, which felt like something kept “pushing” the participants harder and harder all the way. The “No dwell” feedback did not include the continuous “pushing” vibration during the dwell time progression, yet the key strokes were felt so fast that the participants felt like being pushed to leave one key immediately after “click” took place. The participants were not sure when the dwell time had started and they only received the end point. From this perspective, the “Warning” feedback, which not only gave the participants both the starting and ending feedbacks, but also the intervals between them, provided the participants a comfortable pace in the text entry procedure.

Moreover, in some other gaze interactive tasks which do not repeat as often as typing a key, such as menu selection or game playing, users may prefer even longer dwell duration. In those situations, the clear feedback for dwell time progression, such as ascending vibration, may be feasible to prevent errors.

The summarized experiment survey (Appendix 6) also presented a different result from feedback questionnaire (Appendix 5). The feedback questionnaire was filled immediately after the participant experienced a specific feedback and the result of experiment survey was collected after the participant had experienced three feedbacks in a specific order. The result of experiment survey reflected the “preference” more generally while the result of feedback questionnaire explained the preference in more detailed aspects. The different timing of the surveys produced different results. The present results about general preference showed a conspicuous bias to “No dwell” feedback in both sessions. The preference of “Ascending” feedback decreased sharply and the preference of “Warning” increased substantially in the second session. The changes of the preference of “Ascending” and “Warning” feedbacks matched the results of feedback questionnaire. Participants’ opinion on “No dwell” feedback was broadly positive compared with the other two kinds of feedbacks at the end of both sessions, despite the negative perceptions when the participants were queried immediately after their test experience. The reason for the results of the experiment survey (Appendix 6) may include several aspects:

First, the participants completed training before the real tests in the first session, so they might have already gotten used to the continuous feedback of dwell time progression from the training. Thus they might have preferred the “Ascending” feedback in that session, because it was the only one that included the continuous vibration for dwell time progression.

Secondly, learning might be the main reason for the differences in the preference between the two sessions. In the first session, the participants did not have the experience of dwell time feedback, so the “Ascending” vibration gave them a guided feedback which was more natural to mapping the cognitive process when the participants were using the eye typing software. However, the participants might not need the guided dwell time feedback anymore in the second session.

7. Conclusions and future work

As a conclusion, the different feedback conditions did not impact on the dependent variables in this experiment except the increase in KSPC with “Ascending” feedback in the first session. Moreover, tactile feedback on dwell time progression did not improve text entry performance. On the contrary, some tactile feedbacks such as “Ascending” feedback seemed to lead to decreased performance.

In this experiment, the visual feedback was probably so dominant (see section 4.2 which described the experimental keyboard and its visual feedback) that haptic feedback was ignored. Other situations without visual feedback might benefit from haptic feedbacks more. Furthermore, since some participants commented that they tended to focus on the selection feedback to ignore the feedbacks for dwell time progression, a future study of comparing conditions with and without selection feedback could be suggested.

At the very beginning of the thesis work, comparing tactile feedback with auditory and visual feedbacks for dwell time progression was also suggested. However, due to time limitation, this kind of comparison was cancelled in this experiment. Although the result from this research showed that the continuous tactile feedback for dwell time progression was not favorable for the participants, it did not necessarily mean that any other tactile feedback for dwell time progression was not applicable. After all, there are so many kinds of continuous feedback which could be tested. Besides, the actuator used in current research might not be an optimal one to provide the tactile feedback in eye typing. There might be other options and designs for better tools.

More and more multimodal interactions are being studied in the field of human-technology interaction. Visual, auditory and tactile feedbacks are combined to improve the interaction. However, combination is not simply adding. Combination should be made under the consideration of different elements, cutting down some parts of each element if necessary to improve the efficiency of the whole system. Combination could also enlarge the group of potential users of the system. For example, the people with motor disabilities may also suffer from auditory disability, and thus they cannot use the systems which only offer auditory feedbacks. In this sense, how to effectively and efficiently combine different feedbacks in one system to satisfy more users could be one topic of further research.

Last but not the least, interdisciplinary research should be adopted frequently in the field of human-technology interaction and human study should also be very thorough to guide the technique design. For further study, it would be interesting to find explanations and support for the results of the experiment from the viewpoint of neuroscience. For example, which parts of brain are activated when the participants are receiving the stimulation of vision and touch and how they can be connected between each other? What are the differences among the brain reactions when the body is receiving different kinds of tactile stimulation? It could also be helpful to find out what kind of feedbacks should be evaluated based on the neuroscience research and cognitive psychology prior to the evaluation of different feedbacks in the future.

References

Ashmore, M., Duchowski, A.T., & Shoemaker, G. (2005) Efficient eye pointing with a fisheye lens. *Proceedings of Graphics Interface 2005*(GI'05), pp. 203-210. Ontario, Canada: Canadian Human-Computer Communications Society (CHCCS).

Audacity. (2013) Audacity audio editor and recorder software version 2.0.2. Available at http://audacity.sourceforge.net/ (accessed 27 July 2013).

Bates, R. (2002) Have patience with your eye mouse! Eye-gaze interaction with computers can work. *Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology* (CWUAAT'02), pp. 33-38. Available at http://www.cse.dmu.ac.uk/~rbates/Bates7.pdf (accessed 14 February 2009).

Bates, R. & Istance, H.O. (2003) Why are eye mice unpopular? A detailed comparison of head and eye controlled assistive technology pointing devices. *Universal Access in the Information Society* **2**(3), pp. 280-290.

Bates, R., Istance, H.O. & Vickers, S. (2008) Gaze interaction with virtual on-line communities. *Designing Inclusive Futures*, pp. 149-162. London: Springer.

Bee, N. & Andre, E. (2008) Writing with your eye: a dwell time free writing system adapted to the nature of human eye gaze. *In Perception in Multimodal Dialogue Systems, LNCS 5078/2008*, pp. 111-122. Springer. Available at http://www.informatik.uni-augsburg.de/lehrstuehle/hcm/publications/2008-PIT/pit08final.pdf (accessed 14 February 2013).

Brewster, S. & Brown, L. M. (2004) Tactons: structured tactile messages for non-visual information display. *In Proceedings of the 5th Australasian User Interface Conference* (AUIC2004), Dunedin, ser. Conferences in Research and Practice in

Information Technology, A. Cockburn, Ed., vol. **28**, pp. 15–23. Dunedin, New Zealand: ACS, 2004, Available at http://crpit.com/confpapers/CRPITV28Brewster.pdf (accessed 10 March 2013).

Calvo, A., Chiò, A., Castellina, E., Corno, F., Farinetti, L., Ghiglione, P.,Pasian, V. & Vignola, A. (2008) Eye tracking impact on quality-of-life of ALS patients. *Computers Helping People with Special Needs* (ICCHP ‘08)*, LNCS 5105/2008*, pp. 70-77. Berlin: Springer.

Challis, B. P. & Edwards, A. D. N. (2001) Design principles for tactile interaction. *In Proceedings of the First International Workshop on Haptic Human-Computer Interaction.* London, pp. 17–24. UK: Springer-Verlag, 2001.

Chapman, J. E. (1991) The use of eye-operated computer system in locked-in syndrome. *In Proceedings of the Sixth Annual International Conference on Technology and Persons with Disabilities* – CSUN’91, Los Angeles, CA.

Chouvardas, V. G., Miliou, A. N. & Hatalis, M. K. (2005) Tactile Displays: a short overview and recent developments. In Proceeding of 5th International Conference on Technology and Automation, October, 2005. Available at http://icta05.teithe.gr/papers/45.pdf (accessed 10 March 2013).

De Luca, A., Weiss, R. & Drewes, H. (2007). Evaluation of eye-gaze interaction methods for security enhanced PIN-entry. In *Processing of the 19th australasian conference on computer-human interaction: Entertaining user interfaces,* pp. 199-202. New York, NY, USA: ACM. Retrieved from http://dl.acm.org/citation.cfm?doid=1324892.1324932

EyeWrite (2012) EyeWrite (updated February 2012). Copyright © 2008-2012 Jacob O. Wobbrock. Available at http://depts.washington.edu/ewrite/eyewrite.html (accessed 08 May 2013).

Fejtová, M., Fejt, J. & Lhotská, L. (2004) Controlling a PC by eye movements: The MEMREC project. In K. Miesenberger, J. Klaus, W. Zagler & D. Burger (Eds.), *Proceedings of Computers Helping People with Special Needs: 9th International Conference (ICCHP2004)*. Lecture Notes in Computer Science, 3118, pp. 770-773.

Frey, L. A., White, K. P. Jr. & Hutchinson, T. E. (1990) Eye-gaze word processing. *IEEE Trans. Systems, Mans, and Cybernetics, **20** (4)*, pp. 944-950.

Gemperle, F., Ota, N. & Siewiorek, D. (2001) Design of a wearable tactile display. *In Fifth International Symposium on Wearable Computers,* 2001, pp. 5–12.

Grauman, K., Betke, M., Lombardi, J., Gips, J. & Bradski, G.R. (2003) Communication via eye blinks and eyebrow raises: Video-based human-computer interfaces. *Universal Access in the Information Society* **2** (4), pp. 359-373.

Hansen, D.W., Hansen, J.P., Nielsen, M., Johansen, A.S. & Stegmann, M.B. (2002) Eye typing using Markov and active appearance models. *Proceedings of the Sixth IEEE*

Workshop on Applications of Computer Vision (WACV' 02), pp. 132-136. IEEE Computer Society.

Hansen, D. W., Skovsgaard, H. H., Hansen, J. P. & Møllenbach, E. (2008) Noise tolerant selection by gaze-controlled pan and zoom in 3D. *Proceedings of the Eye Tracking Research & Applications Symposium* (ETRA 2008), pp. 205-212. ACM, New York, NY.

Hansen, J.P., Hansen, D.W. & Johansen, A.S. (2001) Bringing gaze-based interaction back to basics. In C. Stephanidis (Ed.) *Universal Access in HCI (UAHCI): Towards an Information Society for All - Proceedings of the9th International Conference on Human-Computer Interaction* (HCII'01), pp. 325-328. Mahwah, NJ: Lawrence Erlbaum Associates.

Hansen, J.P., Johansen, A.S., Hansen, D.W., Itoh, K. & Mashino, S. (2003) Command without a click: dwell time typing by mouse and gaze selections. In M. Rauterberg, M. Menozzi and J. Wesson (Eds.) *Proceedings of 9th IFIP TC13 International Conference on Human-Computer Interaction* (INTERACT' 03), pp. 121-128. Amsterdam: IOS Press.

Hansen, J.P., Tørning, K., Johansen, A.S., Itoh, K. & Aoki, H. (2004) Gaze typing compared with input by head and hand. *Proceedings of the Symposium on Eye Tracking Research & Applications* (ETRA '04), pp. 131-138. New York: ACM Press.

Hart, S. G. & Staveland, L. E. (1998) Development of the NASA-tlx (Task Load Index): Results of empirical and theoretical research, in Human Mental Workload, pp. 139-183. Elsevier, 1988.

Hori, J., Sakano, K. & Saitoh, Y. (2004) Development of communication supporting device controlled by eye movements and voluntary eye blink. *Proceedings Engineering in Medicine and Biology Society, 2004.IEMBS '04. 26th Annual International Conference of the IEEE* **2**, pp. 4302-4305.

Hornof, A., Cavender, A. & Hoselton, R. (2004) EyeDraw: a system for drawing pictures with eye movements. *Proceedings of the 6thInternational ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS' 04), pp. 86-93. New York: ACM Press.

Hothersall D. (2004) History of psychology, chapter seven, McGraw-Hill Humanities/Social Sciences/Languages; 4 edition.

Howe., R. D. & Matsuoka., Y. (1999) Robotics for surgery. Annual Review of Biomedical Engineering, 1999.

Huckauf, A. (2005) Controlling computers by eyes while reducing midas touch-problems. In M. Groner, R. Groner, R. Müri, K. Koga, S. Raess & P, Sury (Eds.) *Journal of Eye Movement Research Special Issue: Abstracts of the Thirteenth*

European Conference on Eye Movements (ECEM13), PB-184, pp. 111. Available at http://www.jemr.org/online/1/s2 (accessed 14 February 2009).

Huckauf, A., Goettel, T., Heinbockel, M. & Urbina, M.H. (2005) What you don't look at is what you get: anti-saccades can reduce the Midas touch-problem. *Proceedings of the 2nd Symposium on Applied Perception in Graphics and Visualization* (APGV ‘05), pp. 170. New York: ACM Press.

Huckauf, A. & Urbina, M. (2007) Gazing with pEYE: new concepts in eye typing. *Proceedings of the 4th Symposium on Applied Perception in Graphics and Visualization* (APGV'07), pp. 141-141. New York: ACM Press.

Huckauf, A. & Urbina, M.H. (2008) Gazing with pEYEs: Towards a universal input for various applications. *Proceedings of the Symposiumon Eye tracking Research & Applications* (ETRA'08), pp. 51-54. New York: ACM Press.

Hutchinson, T.E., White, K.P., Martin, W.N., Reichert, K.C. & Frey, L.A. (1989) Human‑computer interaction using eye-gaze input. *IEEE Transactions on Systems, Man, and Cybernetics* **19**(6), pp. 1527-1534.

I4CONTROL (2008) available at http://www.i4control.eu/ (accessed 06 February 2013).

Istance, H.O., Spinner, C. & Howarth, P.A. (1996) Providing motor impaired users with access to standard Graphical User Interface (GUI)software via eye-based interaction. *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies*(ECDVRAT’96), pp. 109-116. Available at http://www.icdvrat.reading.ac.uk/1996/papers/1996_13.pdf (accessed 13 February 2013).

Jacob, R. J. K. (1991) The use of eye movements in human-computer interaction techniques: What you look at is what you get. *ACM Trans InfSyst,* **9**(2), pp. 152-169.

Jacob, R.J.K. (1995) Eye tracking in advanced interface design. In W. Barfield and T. A. Furness (Eds.) *Virtual Environments and Advanced Interface Design*, pp. 258-288. New York: Oxford University Press.

Kieninger, T. (1996) The “growing up” of hyperbraille an office workspace for blind people,” *in UIST ’96: Proceedings of the 9th annual ACM symposium on User interface software and technology*. New York, NY, pp. 67–73. USA: ACM Press, 1996.

Lund, A. (2001) Measuring usability with the USE questionnaire. *Usability and User experience Newsletter* of the STC Usability SIG. Available at http://www.stcsig.org/usability/newsletter/0110_measuring_with_use.html (accessed 21 February 2013)

Lylykangas, J., Surakka, V., Rantala, J., Raisamo, J., Raisamo, R. & Tuulari, E. (2009) Vibrotactile information for intuitive speed regulation. In *Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating*

People and Technology (BCS-HCI '09). British Computer Society, Swinton, UK, UK, pp. 112-119.

MacDonald, A. (1998) Symbol systems. In Allan Wilson (Ed.) *Augmentative Communication in Practice: An Introduction* (2nd ed.), pp. 19-26.

MacKay, D.J.C. (2006) Dasher Manual. Available at http://www.inference.phy.cam.ac.uk/dasher/download/papers/Manual.pdf (accessed 29 January 2013).

MacKenzie, I.S. (2002) KSPC (keystrokes per character) as a characteristic of text entry techniques. *Proceedings of the Fourth International Symposium on Human-Computer Interaction with Mobile Devices* (MobileHCI' 02), pp. 195-210. Heidelberg: Springer-Verlag.

MacKenzie, I.S. (2003) Motor behaviour models for human-computer interaction. In J. M. Carroll (Ed.), *Toward a Multidisciplinary Science of Human-Computer Interaction,* pp. 27-54. Morgan Kaufmann.

MacKenzie, I.S. & Soukoreff, R.W. (2003) Phrase sets for evaluating text entry techniques. *Extended Abstracts on Human Factors in Computing Systems* (CHI' 03), pp. 754-755. New York: ACM Press.

Majaranta, P. (2009) Text entry by eye gaze. Dissertations in Interactive Technology, number 11, University of Tampere (ISBN 978-951-44-7786-7). Also available in Acta Electronica Universitatis Tamperensis; 869 (978-951-44-7787-4).

Majaranta, P., Ahola, U.-K. & Špakov, O. (2009) Fast gaze typing with an adjustable dwell time. *Proceedings of the 27th International Conference on Human Factors in Computing Systems* (CHI'09), pp. 357-360. New York: ACM Press (DOI: 10.1145/1518701.1518758).

Majaranta, P., Aula, A. & Räihä, K.-J. (2004) Effects of feedback on eye typing with a short dwell time. *Proceedings of the Symposium on Eye Tracking Research & Applications* (ETRA' 04), pp. 139-146. New York: ACM Press (DOI: 10.1145/968363.968390).

Majaranta, P. & Räihä, K.-J. (2007) Text entry by gaze: utilizing eye tracking. In I. S. MacKenzie and K. Tanaka-Ishii (Eds.) *Text Entry Systems: Mobility, Accessibility, Universality*, pp. 175-187. San Francisco: Morgan Kaufmann.

Majaranta, P. & Räihä, K.-J. (2002) Twenty years of eye typing: systems and design issues. *Proceedings of the Symposium on Eye Tracking Research & Applications - ETRA 2002,* pp. 15-22. New York: ACM.

Majaranta, P., MacKenzie, I. S., Aula, A. & Räihä, K.-J. (2003) Auditory and visual feedback during eye typing. *Extended Abstracts of the ACM Conference on Human Factors in Computing Systems* (CHI' 03), pp. 766-767. New York: ACM Press (DOI: 10.1145/765891.765979).

Majaranta, P., MacKenzie, I.S., Aula, A. & Räihä, K.-J. (2006) Effects of feedback and dwell time on eye typing speed and accuracy. *Universal Access in the Information Society* **5**(2), pp. 199-208.

Microsoft Excel. (2010) Microsoft excel professional plus 2010 version 14.0.6123.5001. Available at http://office.microsoft.com/en-001/ (accessed 30 July 2013).

Miniotas, D., Spakov, O. & Evreinov, G. (2003) Symbol creator: an alternative eye-based text entry technique with low demand for screen space. P*roceedings of INTERACT 2003.* Available at http://www.cs.uta.fi/hci/gaze/docs/INTERACT03-Miniotas.pdf (accessed 14 February 2013).

Myers, D. G. (2004) Exploring psychology (6th ed.). Macmillan, pp. 140–141. ISBN 978-0-7167-8622-1.

Nielsen, J., (2000) Why you only need to test with 5 users. Jakob Nielsen's Alert box: March 19, 2000. Available at http://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/ (accessed 22 February 2013).

Špakov, O. (2013). Software: AltTyping. Available at http://www.sis.uta.fi/~csolsp/downloads.php (accessed 19 April 2013).

Pd-extended. (2013) Pd-extended audio synthesizer software version 0.43.1. Available at http://puredata.info (accessed 27 July 2013).

Perlin, K. (1998) Quikwriting: continuous stylus-based text entry. In *Proceedings of the 11th annual ACM symposium on User interface software and technology* (UIST '98). ACM, New York, NY, USA, pp. 215-216. DOI=10.1145/288392.288613 http://doi.acm.org/10.1145/288392.288613.

Porta, M. & Turina, M. (2008) Eye-S: a full-screen input modality for pure eye-based communication. *Proceedings of the Symposium on Eye Tracking Research and Applications* (ETRA '08), pp. 27-34. New York: ACM Press.

Poupyrev, I., Maruyama, S. & Rekimoto, J. (2002) Ambient touch: designing tactile interfaces for handheld devices. *In UIST '02: Proceedings of the 15th annual ACM symposium on User interface software and technology.* New York, NY, pp. 51–60. USA: ACM Press, 2002.

Räihä, K.J. & Ovaska, S. (2012) An exploratory study of eye typing fundamentals: dwell time, text entry rate, errors, and workload. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12). ACM, New York, NY, USA, 3001-3010. DOI=10.1145/2207676.2208711 http://doi.acm.org/10.1145/2207676.2208711 (accessed 26 February 2013).

Rantala, J. & Raisamo, J. (2011) HUI 2011: Tactile sensing & Feedback. Unpublished lecture slides.

Richter, H. & Schmidmaier, M. (2012) Towards simulating push button behavior on touch surfaces. *In Proceeding of 6th International ACM Conference on Tangible,* *Embedded and Embodied Interaction* - TEI 2012, Work in Progress, Kingston, ON, Canada, February 19-22. 2012.

Shuttleworth, M. (2009) Counterbalanced measures design. Explorable. May 8, 2009. Available at http://explorable.com/counterbalanced-measures-design (accessed 25 July 2013).

Smith, W. J. (1996) ISO and ANSI ergonomic standards for computer products: A guide to implementation and compliance. Prentice Hall, New York, 1996.

Snyder, C. (2003) Paper prototyping: the fast and easy way to design and refine user interfaces (interactive technologies). Morgan Kaufmann; 1 edition (April 16, 2003).

Soukoreff, R.W. & MacKenzie, I.S. (2001) Measuring errors in text entry tasks: An application of the Levenshtein string distance statistic. *Extended Abstracts on Human Factors in Computing Systems* (CHI' 01), pp. 319-320. New York: ACM Press.

Soukoreff, R.W. & MacKenzie, I.S. (2003) Metrics for text entry research: An evaluation of MSD and KSPC, and a new unified error metric. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI ' 03), pp. 113-120. New York: ACM Press.

Surakka, V., Illi, M. & Isokoski, P. (2004) Gazing and frowning as a new technique for human‐computer interaction. *ACM Transactions on Applied Perception* **1**(1), pp. 40-56.

Swenson, Rand S. (2006) Review of clinical and functional neuroscience. Available at http://www.dartmouth.edu/~rswenson/NeuroSci/chapter_3.html (accessed 10 March 2013).

Tobii (2011) Tobii T60 & T120 eye tracker, revision 4.Tobii technology. Available at http://www.tobii.com/Global/Analysis/Downloads/User_Manuals_and_Guides/Tobii_T60_T120_EyeTracker_UserManual.pdf?epslanguage=en (accessed 23 February 2013).

Ward, D.J., Blackwell, A.F. & MacKay, D.J.C. (2000) Dasher – a data entry interface using continuous gestures and language models. *Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology* (UIST' 00), pp. 129-137. New York: ACM Press.

Ward, D.J. & MacKay, D.J.C. (2002) Fast hands-free writing by gaze direction. *Nature* **418**(6900), pp. 838.

Ware, C. & Mikaelian H.H. (1987) An evaluation of an eye tracker as a device for computer input. *Proceedings of the SIGCHI/GI conference on Human factors in computing systems and graphics interface* (CHI and GI'87), pp. 183-188. New York: ACM Press.

Wikipedia, Amyotrophic lateral sclerosis. http://en.wikipedia.org/wiki/Amyotrophic_lateral_sclerosis (accessed 29 January 2013).

Wikipedia, Gestalt psychology. http://en.wikipedia.org/wiki/Gestalt_psychology (accessed 31 October 2013)

Wobbrock, J.O., Rubinstein, J., Sawyer, M. & Duchowski, A.T. (2007) Not typing but writing: Eye-based text entry using letter-like gestures. *Proceedings of the 3rd Annual Conference on Communication by Gaze Interaction* (COGAIN '07), De Montfort University, Leicester, UK (September 3-4, 2007). IST FP6 European Project, pp. 61-64.

Wobbrock, J.O., Rubinstein, J., Sawyer, M.W. & Duchowski, A.T. (2008) Longitudinal evaluation of discrete consecutive gaze gestures for text entry. *Proceedings of the ACM Symposium on Eye Tracking Research and Applications* (ETRA ’08), Savannah, Georgia (March 26-28, 2008). New York: ACM Press, pp. 11-18.

Yamada, M. & Fukuda T. (1987) Eye word processor (EWP) and peripheral controller for the ALS patient. *IEEE Proceedings Physical Science, Measurement and Instrumentation, Management and Education* **134**(4), pp. 328-330.

APPENDIX 1 SCRIPT FOR SESSION 1

1, INTRODUCTION AND BACKGROUND QUESTIONNAIRE

Hi, thank you for coming! (You can put your coat and bag here. (Point to the rack and chair)) Do you have your phone with you? I'd like to ask you to turn the volume off. In this research, I will run the test together with you in the test room. So, please come in to the test room and sit down in front of the monitor.

(Lead and guide the participant to sit down in the right place)

Please read the informed consent form.

(Hand the "informed consent form")

If you agree, can you sign it and also fill in this background questionnaire.

(Hand the "background questionnaire")
(Get back the form and questionnaire)

Thank you!

2, INTRODUCTION TO THE EXPERIMENT

Now I will introduce the procedure and details about the experiment.
First, please look at the window in front of you. This is the eye typing software. As you can see, there is a virtual keyboard. When you look at a certain letter for a certain long time, the system will automatically enter that letter into the writing space. The writing space is just above the keyboard. This certain long time is named dwell time. If you moved your eye point from that letter before the dwell time is reached, that letter will not been entered. In our tests, there will be feedbacks for the dwell time progression, which are vibrations your finger can feel from this button.

(Show the button)

The three kinds of feedbacks include:
First, ascending vibration for dwell time progression and click feedback,
Second, a slight vibration at the beginning of dwell time progression and click feedback,
Third, no indication for dwell time progression and only click feedback.
The feedbacks will be given in random order. There will be one kind of feedback in each test and totally there will be three tests.
Before each test, I will calibrate the system in detection of your eye points and then I will ask you to enter 5 min sentences as training part before the real tests. Each real test will last in fixed 5 minutes and totally there will be three tests. You will write sentences according to the given sentences. The given sentences will appear above the writing space in red text. You should write as correct and as fast as you can. If you find an error immediately, you are supposed to correct it. If the error is

in the middle of the text, you are not supposed to delete more than two letters to correct it. You can only delete the text by clicking the backspace (←) key.

(Show the key)

You should also notice the capital letters and the punctuations. You can turn the keyboard into capital letters by clicking the shift key.

(Show the key)

After you entered a full sentence, you can go to next sentence by clicking on the key of smile face.

(Show the key)

After the 5 minutes expired, the system will automatically stop.
After each test, you will fill a questionnaire relating to the test. After three tests, you will fill another questionnaire relating to comparison among the three kinds of feedbacks. And then we will have a short interview.
Do you have any questions about the procedure?
Now I will calibrate the system for your eyes.

(Open the calibration function and start)

Please try to keep your eyes looking at the ball.
Ok, it seems good now. We can start the tests.

3, TEST PROCEDURE

Before the real test, I'd like to ask you to enter 5 minutes sentences as training part. In this part, there will be animation of drawing a circle around the key to indicate the dwell time progression and there will not be any tactile feedback for dwell time progression, only the sharp vibration for click moment provided.

(The participant writing the sentences as real test)

Now as you have already known how to use the system, we can start the real test. I should calibrate the system for your eyes again.

(Open the calibration function and start)

Please try to keep your eyes looking at the ball. Ok, it seems good now. We can start the tests.

First/secondly/thirdly, we will use _(change for each test)_ as the feedback of eye typing procedure. Please put your finger on the button, just put, do not press hardly. You should write as many sentences as you can in 5 minutes. Ready, Go.

(After the participant finish the test)

Ok, Great! Please fill in this questionnaire for the first/second/third kind of feedback.

(Hand the questionnaire)
(Get back the questionnaire)

Thank you! As all the tests finished, I'd like to ask you to fill in the last questionnaire about the comparison among these feedbacks.

(Hand the questionnaire)
(Get back the questionnaire)

Thank you! At last, we have a short interview.

(Ask questionnaire according to interview questions)

4, DEBRIEF

Do you have some thoughts or comments that you would like to share?
Do you still have some questions?
Thank you very much for participating! Remember to come for next session at (time) of (date)

APPENDIX 2 SCRIPT FOR SESSION 2

1, INTRODUCTION

Hi, thank you for coming for the second session! (You can put your coat and bag here. (Point to the rack and chair)) Do you have your phone with you? I'd like to ask you to turn the volume off. In this session, I will also run the test together with you in the test room. So, please come in to the test room and sit down in front of the monitor.

(Lead and guide the participant to sit down in the right place)

2, INTRODUCTION TO THE EXPERIMENT

This session is generally similar with the last session. I only remove the training part as you have already known what the dwell time is. The order of the three feedbacks will be changed. The purpose of this session is to investigate the learning effect. You will also have three tests in this session and a questionnaire after each test and a comparison questionnaire and interview after three tests.

3, TEST PROCEDURE

First/secondly/thirdly, we will use <u>(change for each test)</u> as the feedback of eye typing procedure. Please put your finger on the button, just put, do not press hardly. You should write as many sentences as you can in 5 minutes. Ready, Go.

(After the participant finish the test)

Ok, Great! Please fill in this questionnaire for the first/second/third kind of feedback.

(Hand the questionnaire)(Get back the questionnaire)

Thank you! As all the tests finished, I'd like to ask you to fill in the last questionnaire about the comparison among these feedbacks.

(Hand the questionnaire)(Get back the questionnaire)

Thank you! At last, we have a short interview.

(Ask questionnaire according to interview questions)

4, DEBRIEF

Do you have some thoughts or comments that you would like to share?
Do you still have some questions?
Thank you very much for participating! Here is the movie ticket that you are deserved for participating this experiment.

APPENDIX 3 INFORMED CONSENT FORM

Study Administrator is: Jingjing Zhi

TAUCHI, University of Tampere
Kanslerinrinne 1, 33014

This is a study about feedback for dwell time progression in eye typing systems intended for people who are with motor disabilities. Our goal is to measure the effectiveness, efficiency and user-friendliness of the feedbacks. Your participation will help us accomplish this goal.

In this session, you will be working with a prototype of system. We'll ask you to try three feedbacks for eye typing procedure. Which are ascending vibration for dwell time progression, a slight vibration for dwell warning and no indication for dwell time progression (order will be given in random). I will sit in the same room, quietly observing the session and taking notes.

All information we collect concerning your participation in the session belongs to TAUCHI and will be used for our internal research purposes. We will not use videotape or audio tape the session. The performance of the system will be recorded by the software itself. We may publish our notes from this and other sessions in internal reports, but all such observations will be confidential and will not include your name.

This is a test of the feedback of the system—we are not testing you! We want to find out what aspects of the feedbacks are not feasible so that we can make it better or decide whether to adopt it or not.

To the best of our knowledge, there are no physical or psychological risks associated with participating in this study, which will last approximately 1 hour. You may take breaks as needed and may stop your participation in the study at any time.

Statement of Informed Consent

I have read the description of the study and of my rights as a participant. I voluntarily agree to participate in the study.

Print Name: ____________________

Signature: ____________________

Date: ____________________

APPENDIX 4 BACKGROUND QUESTIONNAIRE

Age: ______________

Gender: [ ] Male [ ] Female

Sight:

[ ] Normal [ ] Corrected (Glasses or contact lenses) [ ] Others___________

Hearing:

[ ] Normal [ ] Problem? Please describe___________________________________

Sense of Touch:

[ ] Normal [ ] Problem? Please describe___________________________________

Any experience with gaze interaction systems?

[ ] No [ ] Yes (describe) ____

Any experience with eye typing systems?

[ ] No [ ] Yes (describe) ____

Any experience with haptic interaction systems?

[ ] No [ ] Yes (describe) ____

APPENDIX 5 FEEDBACK QUESTIONNAIRE

Workload

Please select the workload level for each of below parameters.

	Very Low						Very High
Mental Demand How mentally demanding was the task?	1	2	3	4	5	6	7
Physical demand How physically demanding was the task?	1	2	3	4	5	6	7
Effort How hard did you have to work to accomplish your level of performance?	1	2	3	4	5	6	7
Temporal demand How hurried or rushed was the pace of the task?	1	2	3	4	5	6	7
Frustration level How insecure, discouraged, irritated, stressed and annoyed were you?	1	2	3	4	5	6	7
Performance How successful were you in accomplishing what you were asked to do?	1	2	3	4	5	6	7

Comfort

Please select the comfort level for each of below parameters.

	Very Low						Very High
Eye comfort	1	2	3	4	5	6	7

PLEASE TURN OVER !

Ease of use

Please select your own feeling about the ease level for each of below parameters.

	Very Low						Very High
Pointing accuracy	1	2	3	4	5	6	7
Text entry speed	1	2	3	4	5	6	7
System control How do you feel you are in control of the whole process?	1	2	3	4	5	6	7
Simple to use	1	2	3	4	5	6	7

Ease of Learning

Please select level of agreement to the following statements.

	Totally agree						Totally disagree
It is easy to learn to use it.	1	2	3	4	5	6	7
I use the system much faster in the end than in the beginning.	1	2	3	4	5	6	7

Free comment:

____

____

____

____

____

APPENDIX 6 EXPERIMENT QUESTIONNAIRE

Please select the right answer of the following questions based on your experience of the tests.

Ascending =↗ +Click; Warning = Slight warning+Click; No dwell = only Click.

Which one of the feedbacks do you prefer?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks would you like to use for longer time?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks requires lowest cognition load?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks requires lowest physical load?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks is most comfortable for use?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks is easiest for use?

☐ Ascending ☐ Warning ☐ No dwell

Which one of the feedbacks is most easily to learn how to use?

☐ Ascending ☐ Warning ☐ No dwell

Free comments:

____

____

____

____

____

____

APPENDIX 7 INTERVIEW QUESTIONS

In the process of your tasks, do you have any difficulties? What are them?

Which feedback do you think is the best one? Why?

Which one of the feedbacks is most intuitive?

Do you have any suggestions for modifying the feedbacks? (if any, focus on the haptic feedbacks)

Backup: Do you think haptic feedback can be an effective feedback for indicating the dwell time progression in this eye typing interaction?

Free comments: